University of Alberta

Drinking Water Safety and Risk Management for Public Health Professionals

by

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To Mihaela

ABSTRACT

Drinking water outbreaks continue to occur in Canada despite major advances in public health and water treatment for over a century. The study employed direct interviews with medical officers and experienced public health inspectors (PHIs) in Canada and Australia, and a mailed questionnaire to PHIs in Western Canada to understand current public health practices to assure drinking water safety. Except for a few regional initiatives, public health agencies play a largely reactive role in assuring drinking water safety. While municipal drinking water in cities is generally safe, many small community and non-residential water systems cannot consistently assure safety. Recently, a risk-based quality management approach to drinking water is being adopted in many affluent countries to address similar issues. Safe drinking water represents a major population health primary prevention measure. Public health professionals should be supported and trained to participate in a truly proactive, upstream prevention approach to drinking water safety.

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LIST OF ABBREVIATIONS

BWA	Boil water advisory
CDC	Centers for Disease Control and Prevention
CIPHI	Canadian Institute of Public Health Inspectors
DALY(s)	Disability Adjusted Life Year(s)
DBP(s)	Disinfection by-product(s)
DSe	Diagnostic sensitivity
DSp	Diagnostic specificity
EHM(s)	Environmental health manager(s)
EHO(s)	Environmental health officer(s)
EHP(s)	Environmental health program(s)
EPA	Environmental Protection Agency
FTE	Full-time equivalents
HREB	Health Research Ethics Board
MOH(s)	Medical officer(s) of health
NPV	Negative predictive value
PHI(s)	Public health inspector(s)
PPV	Positive predictive value
RHA(s)	Regional health authority(ies)
THM(s)	Trihalomethane(s)
UV	Ultraviolet radiation
WHO	World Health Organization

1. GENERAL INTRODUCTION

1.1 Rationale

Despite major advances in water treatment in the last 150 years, drinking water related outbreaks continue to occur. Current approaches have reduced their frequency and their impact on population, but they are far from completely protecting the public. Moreover, such successes sometimes tend to encourage complacency among those involved in protecting public health. There is scope to further reduce the occurrence of such incidents with current technologies, but an integrated risk management approach is necessary.

Public health professionals have a mandate to protect the public from health risks, including water-borne diseases. This responsibility cannot be entirely delegated to water treatment professionals, who are normally expected to provide drinking water within certain specified parameters, but lack public health and health risk management training.

Currently in most jurisdictions in Canada public health agencies tend to delegate almost entirely this responsibility to water treatment professionals and only get involved when unusual rates of disease suggest a water-related source. In many cases public health professionals lack an understanding of the issue and how to have a more proactive role.

Public health agencies are responsible to ensure that a consistent and comprehensive risk management strategy is implemented to prevent that drinking water poses any health risks for the population they have a mandate to protect. In fact, public health professionals should be at the forefront of proactive risk management strategies aiming to minimize the occurrence of adverse health events, in close cooperation with water professionals, who are the ones required to implement such strategies.

1.2. Research design

1.2.1. Research hypothesis

Public health agencies need a more active, structured and comprehensive approach in order to accomplish effectively their responsibilities to the public to ensure the safety of drinking water and to prevent occurrence of drinking water related outbreaks.

1.2.2. Research question

What roles and approaches ought public health officials take to better protect the public from drinking water related health risks?

1.2.3. Research objectives

1. Identify how do public health professionals define their role, responsibilities and what approaches do they use to fulfill their public health mandate regarding drinking water safety.
2. Identify what public health professionals understand about the key issues and what critical gaps in their knowledge and training need to be addressed.
3. Identify potential gaps between the currently accepted role, responsibilities and approaches within the public health profession and the provincial regulatory and public expectations to be protected from drinking water related health risks, including the more vulnerable groups (children, elderly, immunocompromised, etc.).
4. In consultation with public health professionals, define practical approaches to address these gaps to enable them to better fulfill their mandate in the area of drinking water safety.

1.2.4. Potential outcomes and significance of research

1. A better understanding of current practice among public health professionals in regards to ensuring drinking water safety.
2. Recommend practical approaches that would enable public health professionals to better fulfill their mandate of protecting the public from drinking water related health risks.
3. Develop the curriculum for a training manual and a short course for public health professionals on health risk management for drinking water.
4. Develop a brief and focused drinking water safety summary document for members of health boards to enable them to ensure that their health authority is discharging its public health responsibilities with regard to drinking water safety in their region.

5. Develop recommendations for regulators that would support a more effective approach to ensure drinking water safety.

1.2.5. Anticipated problems and approaches to address them

1. Time availability and competing priorities for medical officers of health (MOHs) and environmental health managers (EHMs)
   - Approach used: Use flexibility in scheduling the interviews.
2. Provincial legislation may vary:
   - Approach used: Target typical regional health authorities (RHAs) in several provinces.
3. Rural/urban differences:
   - Approach used: Select representative RHAs in each province, to cover both urban and rural areas.

1.2.6 Ethics approval

The study, including research instruments and information letters for participants, were reviewed and approved by the Health Research Ethics Board (HREB) of the Faculty of Medicine and Dentistry, University of Alberta in July 2004.

1.3. Literature review

The English literature available to public health professionals was reviewed to understand the currently accepted practices to assure drinking waters safety in affluent countries, present initiatives to address this issue and the current state of research. For this purpose I reviewed available databases of journals for research articles on the topic as well as textbooks addressed to public health professionals. I also reviewed the literature introducing regulatory frameworks for drinking water management in English-speaking countries to understand various approaches to drinking water safety. Publications included in this review are organized on two categories, depending on the prevalent focus: background literature on water-related health hazards and water treatment solutions, and literature on the management of drinking water safety. The review did not include technical literature for other professionals, for example on water treatment engineering, since it would have been largely out of the scope of public health. The latter is likely too detailed to be comprehensible to most public health professionals.

1.3.1 Literature on water-related health hazards and drinking water treatment for environmental health professionals

The "Handbook of Environmental Health and Safety", volume 2: Principles and Practices (Koren and Bisesi 1996), although somewhat outdated, provides fairly detailed background information on public and private water supplies and on water pollution and water quality controls. It presents the legal and scientific background for drinking water supplies in United States (U.S.). It also addresses water treatment in a manner easy to understand for environmental health professionals. Water supply problems are organized on water source, water system, water treatment and disinfection, and environmental contamination. The chapter on water supplies includes information on environmental surveys for groundwater and surface water sources, and water treatment plant surveys, recommendations on water sampling and information on coliform testing. The chapter on water pollution presents information on surveys of industrial waste and non-point sources of pollution and wastewater treatment. The book also summarizes major EPA initiatives to protect water resources. The focus is only on U.S., and U.S.-developed drinking water standards. The book was published in 1996, thus it does not present any data on preventive, source to tap approaches on management of drinking water quality. While the book acknowledges occasionally that raw and finished water monitoring may not tell the whole story about drinking water safety, this point is likely missed by the emphasis on EPA maximum contaminant levels (MCLs). Since EPA regulations do not provide any indication on priorities, the list of drinking water standards is presented for biological pathogens (total coliform bacteria, *Giardia*, viruses and *Legionella*), chemical contaminants (67, listed alphabetically), and radioactive contaminants, without any indication of relative importance.

The "Handbook of Environmental Health", 18th edition, (Bassett 1999) is designed as a reference for PHIs in the United Kingdom. The section on water treatment presents a summary of most relevant waterborne health hazards in the U.K. (e.g. *Cryptosporidium*, nitrates); enlists U.K. based finished water standards and sampling instructions; and introduces relevant water treatment processes. The information is basic for new PHIs and it makes no reference to a preventive approach or development of system-specific water safety plans.

The book "Basic Environmental Health" (Yassi et al. 2001) is intended to be a university level textbook. The chapter on water and sanitation provides an introduction to water safety and its relation to sanitation, and discusses major global issues related to water resources management. Its global analysis supports the link between freshwater quantity and quality, with relevant examples from around the world. It also correctly places emphasis on microbial agents as the main threat to public health from drinking water. The book is however intended for a worldwide audience and, thus, presents all issues in very general terms, which does not make it as useful for Canadian practitioners.

The book "Environmental Health", in its 3rd edition (Moeller 2005) intends to incorporate new developments in the field of environmental health. The chapter on drinking water provides an introduction to water sources and major contamination concerns; human uses of water; emerging waterborne diseases and chemical health hazards in drinking water; the principles of new and established water treatment processes; and recommendations on water conservation measures. The book is U.S.-based in many respects. It makes no recommendations on preventive approaches to drinking water safety or development of water safety plans, despite being published after the third edition of World Health Organization (WHO) "Guidelines for Drinking-water Quality" (WHO 2004a), the adoption of the New Zealand risk management guidance (NZMOH 2001) and of the Australian "Framework for Management of Drinking Water Quality" (NHMRC 2004b), all discussed below. It also contains a few inaccuracies related to disinfection by-products, such as ozonation not producing any unwanted by-products.

Many professionals continue to work on improving understanding of current drinking water concerns by developing risk assessment models to answer some of the current questions. For example, Simmons et al. (2001) uses the health risk assessment framework for chemical contaminants to propose a model for microbial health risk assessment for tank rainwater, with an emphasis on using epidemiology to answer some of the questions at various risk assessment stages. The proposed approach could in principle be extrapolated to help public health authorities to identify high-risk areas and assess the effect of interventions aimed at improving drinking water safety in general. However, at the present time there are still major uncertainties in the approach which makes it unfeasible to answer most questions related to management of drinking water safety; but this may improve in the future. In another article, Ashbolt (2004) presents a risk analysis for the long-held view that concerns over disinfection by-products (DBPs) should not compromise control of the microbial contamination in drinking water. The paper uses a risk assessment framework to analyze both pathogen and chemical risks, and outlines the differences between chemical and microbial hazards in respect to health risk assessment. The author uses the example of the risk assessment by Havelaar et al. (2000), developed to compare the benefits of *Cryptosporidium* inactivation by ozonation with cancer risks due to bromate, the most important by-product in this process, using disability adjusted life-years (DALYs). While noting the large range of uncertainties characteristic to many environmental health issues, the authors conclude that benefits of ozonation outweigh risks by at least a factor of at least 10.

1.3.2. Literature on management of drinking water safety

In 1992, Alberta Health commissioned a study of local environmental health programs (EHPs) in Alberta. The study was undertaken by a multidisciplinary team from the University of Alberta Department of Public Health Sciences, and conclusions were presented in several publications (Wanke et al. 1996; Saunders et al. 1996a; Saunders et al. 1996b). The objective of the study was to develop a reference model for EHPs. Drinking water was one of the eight sub-programs included in the analysis and most conclusions of the study are relevant to this field. While EHPs have undergone major structural changes since that time, the most important being their inclusion in the regional health authorities (an umbrella organization for all health care and public health activity in each of the current nine Alberta regions), the study nevertheless provides some useful insights for organization of drinking water safety programs in Canada at present time.

The first article (Saunders et al. 1996a) acknowledges the largely preventive nature of EHPs and proposes a framework for generating measurable objectives for EHPs. These objectives would be structured on three levels: outcome, process and structure. Their description was followed by suggestions for possible objectives and performance indicators and included sample objectives and indicators for illustration purposes. The most important observation for outcome-based targets was to acknowledge the limitations of using health status objectives and indicators to assess the effect of environmental health activity on population health. The authors propose the use of proxy or intermediate risk-reduction objectives and indicators on several levels: transmission chain from hazard source to humans, interventions implemented, and success of intervention strategies. In addition, they introduce incident recording and public satisfaction as outcome objectives. Process objectives and indicators are introduced on two levels:

management and service delivery. Structure objectives and indicators are suggested to assess the various inputs required to perform planned processes.

This paper provides a basis for the organization and performance assessment of drinking water safety programs nowadays. The insights presented suggest that the preventive nature of such programs should be acknowledged by providing them with risk-reduction, rather than simply health status targets. It introduces the idea of incident recording, which can be used for learning as well as for performance evaluation, and of public satisfaction targets, which are important for maintaining public trust in their drinking water quality. The use of process objectives and indicators can provide more clear guidance to managers of water safety programs and improves performance evaluation. Developing structure objectives and indicators assists in assessing necessary inputs for the functioning of these programs. These recommendations have been, to some extent, already translated in practice in Alberta (see below).

The second article (Wanke et al. 1996) inserts the proposed reference model for EHPs into the larger picture of population health. The paper defines the specific area of environmental health and notes several fundamental differences from health care services and from other public health areas, in the view of the recent integration of environmental health activity in the regional health authority (RHA) umbrella: its primary prevention (upstream) focus; the distinction between the intended beneficiaries of service (public) and regulated professionals (e.g. water operators); the complex inter-relations between environmental contaminants and diseases (e.g. cancer) that often preclude establishment of direct causality.

The authors note that environmental health professionals benefit from high public credibility but also express concerns that the broad scope of responsibilities of RHAs may negatively impact the performance and funding of environmental health programs, due to a lack of appreciation for the specifics of this field and the difficulty to assess health status objectives, unlike other RHA programs. Thus they recommend the establishment of a single standing environmental health committee for each region. The paper also makes recommendations on the scope of services and priority areas, and emphasizes the unique position of this sector among other sectors involved (environment, resources, etc.) as having public health as the primary concern. The insights of this paper are relevant for drinking water safety programs since it defines their scope in the large population health picture, emphasizes that primary prevention should be their main focus and notes the potential risks to receiving low priority and funding.

The third paper in this series (Saunders et al. 1996b) presents the conclusions of an analysis on the strengths and obstacles facing EHPs in Alberta and recommends a series of areas of re-alignment to bring them in line with the above presented reference model for EHPs. The re-alignment areas are still relevant for most drinking water safety programs in Canada nowadays: change from reactive to proactive management; widen the range of interventions to include alternatives to enforcement (education, use of market incentives, collaboration); outcomes orientation to assist performance evaluation, shift away from a rule-driven to a mission-driven approach; co-operation with other stakeholders. The authors also present recommendations for strategic planning for EHPs and objectives and indicators for each controlled media, including drinking water.

At the end of the article, the authors present several implementation considerations that are by and large still relevant for drinking water safety at the present time: while the Alberta Public Health Act allows more effective environmental health enforcement, some of the regulations should be assisted by standards developed together with other stakeholders using health risk evidence and a risk analysis approach; changes may be needed to improve efficiency, but increased funding is necessary to enable environmental health programs to fulfill their responsibilities; health boards and senior health system managers need to understand that EHPs operate under a different paradigm than health care services; and professional training and development is necessary to keep environmental health professionals up to date in a rapidly-developing field.

End-of-pipe drinking water monitoring has been for a long time used as primary evidence that a water system provides safe drinking water. Several published articles discuss the limitations of using finished water monitoring results as the sole evidence base for risk management actions (Allen et al. 2000; Hrudey and Leiss 2003; Hrudey and Rizak 2004).

The first article in this list notes that finished water monitoring results have limited value to predict drinking water health risks and inform decision-making, based on several case studies and statistical arguments: low numbers of pathogens in treated water, uneven distribution, large sample volumes, difficult and time consuming laboratory procedures, long time lag, low diagnostic specificity and sensitivity for detection methods, and unknown viability and infectivity of detected pathogens.

The next two articles provide a scientific basis for some of the intuitive insights on the cautious use of laboratory results when looking for rare hazards; i.e. if the probability of a sample being positive is low relative to the overall false-positive rate of the detection method, then positive lab results will represent predominantly false-positives. The insights are valid regardless of the lab reputation, the specific analytical method or equipment employed or the cause of false positives. The issue is recognized in the medical field when screening for disease in low prevalence populations. The application to the drinking water field relates particularly to finished water monitoring, where the final product of water treatment is rarely expected to present health hazards (e.g. coliforms, harmful chemicals).

Building on insights like those mentioned above on the limitations of finished water monitoring to ensure safe water, Hrudey advocates a fundamental change of approach to the management of drinking water quality (Hrudey 2001; Hrudey 2004). In these two articles, the author introduces the concept that drinking water quality management is an exercise in risk management, rather than a technical service to produce a final product that is randomly tested for satisfying a set of numbers (i.e. monitoring for compliance to numerical water quality guidelines).

In the first article (Hrudey 2001), the author introduces ten risk management principles as a basis for a total quality management approach to drinking water quality: proactive rather than reactive management; priorities setting should be based on risks, rather than hazards; aim to achieve the greatest overall risk reduction; recognize human error as inevitable; convert hindsight into foresight; view the larger picture; distinguish evidence from inference; use risk assessment to inform, not to make decisions; accept uncertainty and make best use of available knowledge; and strive for continuous improvement. It additionally suggests ways to close the gap between the comprehensive quantitative risk assessment protocols that require more knowledge than is usually available for a water system and safe drinking water provision, by the use of semi-quantitative and qualitative approaches that are more simple and practical to inform water quality risk management decisions. At the end, it advocates the development of a risk management framework for water quality management, like the one which was being developed at that time in Australia. Such a framework, besides the advantage of allowing for a preventive strategy for drinking water, it would improve accountability and involvement of stakeholders.

In the second article (Hrudey 2004), the author applies the above principles to his experience as member of the Research Advisory Panel for the Walkerton Inquiry. An important note is that failures leading to the tragedy in Walkerton were not caused by less stringent water quality standards, but by oversight and management inadequacies at several levels, resulting in failures to implement well-known practices in the field. This re-emphasizes the need for a total quality management approach to drinking water safety, rather than a narrow, numerical compliance monitoring approach. The author cites a few recommendations from the Walkerton Inquiry, Part 2 report (O'Connor 2002b) to prevent future incidents that support this approach: adoption of best practices and continuous improvement; "real time" process control; operation of multiple safety barriers; preventive rather than reactive risk management strategies; and effective leadership. It notes that water treatment processes cannot be made 100% effective, thus a source to tap, multiple barrier approach is necessary. It also notes Justice O'Connor's recommendation that people responsible for the municipal water system "should be held to a statutory standard of care". A summary of essential risk management messages applicable to drinking water is presented: be preventive rather than reactive; prioritise risks and deal with major ones first; learn from experience; and resources invested should be proportional to the danger. The author underlines the role of complacency as a cause of waterborne outbreaks, using the example of North Battleford *Cryptosporidium* outbreak that took place 11 months after Walkerton. The emphasis of the article is on the need for a total quality management framework for water quality management in Canada, and for the recognition of water operators as public health professionals, who consequently need to receive proper public health training.

The book "Safe Drinking Water - Lessons from Recent Outbreaks in Affluent Nations" (Hrudey and Hrudey 2004) represents a particularly original contribution to the field of drinking water safety management. The authors present the results of an investigation of 70 waterborne outbreaks from 15 affluent countries over the past 30 years as individual case studies. The book introduces the scientific and technical background relevant to drinking water safety in a manner accessible to all public health professionals. Furthermore, each waterborne outbreak is presented and analyzed in a specialist yet accessible manner presenting the background and events, the public health implications, defining causality based on relevant evidence, and linking it to the future learning potential for interested professionals. In particular, the Walkerton outbreak analysis benefits from one of the authors' personal experience serving the Research Advisory Panel of the subsequent judiciary inquiry. The case studies are then followed by identifying key recurring themes and recommendations for preventive management of drinking water safety, including a presentation of current preventive approaches. The book is written in an accessible manner and represents an excellent resource for all professionals involved in the provision or regulatory aspects of drinking water.

Following the Walkerton tragedy in May 2000, specific safe drinking water acts with subsequent regulations have been adopted in Ontario, British Columbia (B.C.) and in Australia (Victoria) to control and regulate drinking water systems and promote a source to tap management of drinking water quality (BC_MHS 2001; OMOE 2002; DHS 2003). The above mentioned acts and regulations also make various provisions for a risk-based approach to management of drinking water quality, requiring source to tap risk assessments and development of risk management plans and emergency response plans for drinking water systems. Each province/ state has its own local approach to drinking water risk management; the Victoria state model is based on the Australian Framework for Management of Drinking Water Quality in the current Australian Drinking Water Guidelines (NHMRC 2004a), presented below. Since the implementation of regulations is still emerging at this time, it is difficult to evaluate the efficiency of any particular approach. Regulations per se may not be enough to assure that quality management (and) best practices are broadly adopted in the water industry.

For Ontario in particular, the Walkerton tragedy has had a strong impact on the drinking water regulatory environment in Ontario. The Walkerton Inquiry Report (O'Connor 2002a; O'Connor 2002b), particularly Part Two of the Report, provides the underlying philosophy and practical recommendations to assure safe drinking water in Ontario in the future. The report makes many recommendations on best practices for a quality management of drinking water (e.g. multiple barrier approach, source protection) as well as on the governmental approach to certification and training of operators, the management of municipal water systems, and for improving drinking water safety for small drinking water systems and for systems serving First Nations.

Since then, the Ontario Ministry of Environment (OMOE), adopted the Safe Drinking Water Act and regulations and amended other related acts and regulations in an ongoing effort to improve drinking water safety in the province. OMOE currently affirms a commitment to systematically implement all the 121 recommendations in the second part of the Walkerton Inquiry report (OMOE 2005a). However, compliance to new regulations created some difficulties for smaller drinking water systems that could not afford, for example, to pay consultants to perform system risk assessments or comply with frequent and comprehensive monitoring requirements. As a result, at present time, OMOE is considering amending regulations and moving some of these small non-municipal systems under public health jurisdiction, which can assist with compliance with these regulations (OMOE 2005b).

While not governed by a specific drinking water act (but with potable water provisions in the Environmental Protection and Enhancement Act for regulated systems, see AE 1993) a "A Common Reference System and Operational Standards for Alberta Regional Health Authority Environmental Health Programs" (The Blue Book) was developed by the Alberta Council of Managers for Environmental Health (AHW 2001). The two pages dedicated to safe drinking water are built on environmental health objectives and include health status and risk-reduction objectives, as well as process standards for water systems not regulated by the Department of Environment and general structure objectives. The framework is a useful reference for drinking water safety in the province and it introduces clear and measurable objectives for this activity. The framework is limited to unregulated water systems and its focus is generally reactive and on end-of-pipe monitoring; it does specify an intent to assess the risk and classify the systems for purposes of finished water monitoring (without a time limit), and it establishes minimal requirements for health promotion and education.

A guidance field manual, now in the second edition, was developed by the Alberta Health based Technical Advisory Committee on Safe Drinking Water (AHW 2004). The manual is an excellent operational reference for field PHIs for bacteriological water monitoring and interpretation; unregulated water system inspection; water treatment and disinfection; public health action protocols; and public information and education materials. While an excellent resource for the current expectations from PHIs in Alberta, the manual is mainly focused on water quality monitoring and system inspection for small unregulated drinking water systems that are the focus of public health activity in this province.

The New Zealand Ministry of Health released in 2001 a risk management framework, "How to Prepare and Develop Public Health Risk Management Plans for Drinking-Water Supplies" (NZMOH 2001), followed by accompanying Guides that detail application to each water supply element. The stated purpose of this guidance was to encourage the use of risk management principles during treatment and distribution by water suppliers, in recognition of the fact that finished water monitoring is largely reactive and untimely in the case of the presence of a health hazard in water, thus its efficiency as the only water quality management technique used is limited. Since most of the country's water supplies are small, the guidance provides a pragmatic algorithm for the development of a system-specific, source to tap risk management plan for small water systems. The guidance can serve as an excellent reference for the development of small systems risk management plans in Canada.

The Bonn Charter for Safe Drinking Water (IWA 2004) is the result of a workshop of senior drinking water experts that first met in 2001 to develop a high-level framework that describes basic operational and institutional arrangements to guide the drinking water industry. The principles of the resulting framework can be adapted to any national or local circumstances. Principles relevant to a risk management approach to drinking water safety include: assessing risk at all points in a water system rather than relying only on compliance monitoring of finished water; the importance of partnership between various stakeholders; transparency of the process; clear definition of different jurisdictions to assure complete system coverage from catchment to consumer; drinking water should be safe, reliable and aesthetically acceptable (IWA 2004, p.9).

In Australia, a "Framework for Management of Drinking Water Quality" was incorporated into the Australian Drinking Water Guidelines developed by the National Health and Medical Research Council (NHMRC 2004b). This comprehensive framework outlines a total quality management approach for the design of a source to tap management of drinking water quality based on 12 elements: commitment to drinking water quality management, assessment of the drinking water supply system, preventive measures for drinking water quality management, operational procedures and process control, verification of drinking water quality, management of incidents and emergencies, employee awareness and training, community involvement and awareness, research and development, documentation and reporting, evaluation and audit, and review and continual improvement. The framework incorporates a preventive risk management approach; it is flexible to allow implementation in each state in Australia; it can be adapted to water systems of any size; and it provides consumers with the means to judge the performance of their water provider.

The evolution of the safe water regulatory environment in the U.S. is presented in Raucher (1996). A more recent update that discusses the complexity of the Safe Drinking Water Act and its subsequent amendments is presented in Pontius (2004). The current US legislation places its main emphasis on meeting numerical guidelines for contaminants rather than on quality management approaches to drinking water management. The Safe Drinking Water Act and its amendments nevertheless specify a number of highly specialized requirements. The WHO "Guidelines for Drinking-water Quality" presented below have benefited substantially from the knowledge base generated by U.S. research. However, the broad principles of risk management are more difficult to isolate in the complex U.S. regulatory scheme.

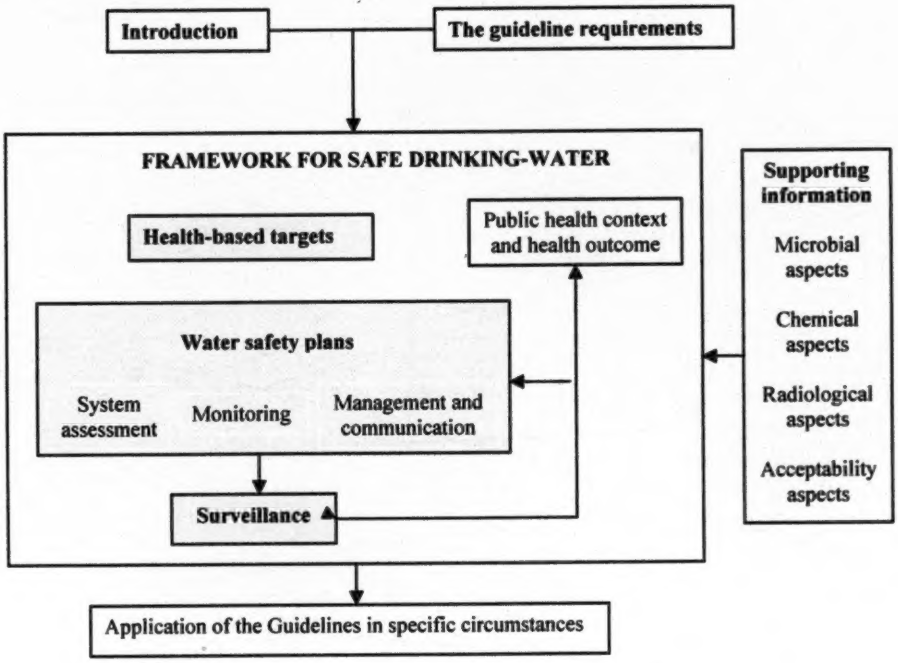
The first volume of the third edition of WHO "Guidelines for Drinking-water Quality" (WHO 2004a) integrates years of research and practice, done by drinking water experts worldwide in drinking water safety in the years since the second edition, in a comprehensive guide for a global audience. This edition introduces the concept of water safety plans in a preventive management framework for safe drinking water founded on health-based targets (Figure 1). The framework is based on many concepts common to earlier Australian and New Zealand drinking water quality management frameworks. It promotes preventive approaches as the primary focus in management of drinking water quality, rather than a major reliance on treated water monitoring against guideline numbers. The Guidelines are also the drinking water quality reference for the European Protocol on Water and Health coming into effect in August 2005, a legally binding document for 35 countries in the WHO European Region. While certain elements have been developed to assist low income countries with major challenges in assuring safe drinking water, most concepts presented are adaptable to the Canadian context.

The preventive risk management approach to safe drinking water is introduced for the Canadian water industry by the document "From Source to Tap: Guidance on the Multi-Barrier Approach to Safe Drinking Water" which is available on Health Canada website (CCME 2004). The guidance promotes recent international preventive approaches, presenting the multiple barrier approach to drinking water safety, recommendations for quality management in the water industry, and the importance of good source water protection and good operating practices. However, as noted in Hrudey (2005) no particular emphasis is placed on this document on the Health Canada website compared to the other documents related to numerical drinking water quality guidelines, making it unclear that this approach is intended to be the overall framework for assuring safe drinking water.

The document "A Population Health and Drinking Water Safety Perspective on Guidelines for Canadian Drinking Water Quality" prepared for the Water Quality and Health Bureau of Health Canada (Hrudey 2005) notes several shortcomings in the Canadian approach to the management of drinking water safety in the international context and proposes a population health approach to drinking water safety. The document defines the role of drinking water treatment in the context of major public health measures to protect population health. Summarizing international developments in the area of drinking water management, the author presents a set of recommendations to make the Canadian Drinking Water Guidelines a truly preventive risk management program. The document is relevant for all public health and water professionals involved in assuring drinking water safety in Canada.

Figure 1 - The WHO framework for safe drinking water

(adapted from WHO 2004a, p.23)



2. METHODS

Two methods were employed to address study objectives:

1. **Interview survey:** Direct interviews with medical officers of health and other public health professionals in Canada and Australia in order to identify assistance and educational needs.
2. **Questionnaire survey:** Mailed questionnaire to public health inspectors / environmental health officers in Alberta, British Columbia and Saskatchewan to assess knowledge and further identify assistance and training needs.

2.1. Interview survey

2.1.1. Interview target group

The interview survey was targeted towards MOHs and EHMs in regional health authorities from various provinces in Canada. For comparison purposes, I also interviewed a sample of their counterparts in two Australian states.

Due of the novelty of research in this field and consequent lack of background data, and to address some of the anticipated problems (see 1.2. Research design), RHAs participating in the study were selected based on a purposive sampling plan that aimed to maximise variation. RHAs included in the study represented typical regions from several provinces/states with different safe water legislation and approaches, cover both urban and rural areas, and are likely to encounter different challenges in assuring drinking water safety. The goals were to identify common patterns that cut across differences between regions, as well as common issues within higher-need areas.

Participants from each RHA were targeted to represent the best combination of people in leadership positions who are also the most informed professionals concerning drinking water safety. However, because of the novelty of this research, I allowed for some flexibility to the suggestions of professionals contacted. For example, as suggested by some medical officers or environmental health managers, I occasionally interviewed public health inspectors (PHIs) who were either water specialists for their team or senior inspectors with many years of experience in water safety. This allowed acquiring data from the best available sources, which was always my primary goal.

2.1.2. Interview content

The interview survey consisted of semi-structured interviews based on 17 open-ended questions. These questions were developed in order to provide some structured inquiry into the practices of the public health profession in regards to drinking water safety. The interview topics were organized in three categories, from general to more specific within each category (Box 1).

Box 1 - Interview topics

I. Role and responsibilities for drinking water safety:

1. *What are the major public health issues that the public health agency has to address in your region?*
2. *How would you define the role of the public health agency in regards to ensuring drinking water safety? Please describe specific responsibilities that you understand for this role.*
3. *What actions do you take to ensure the safety of drinking water in your region?*

II. Approaches to ensure drinking water safety:

4. *How often do you need to answer inquiries about drinking water safety?*
5. *What are the most common concerns?*
6. *Who responds to potential concerns about drinking water safety?*
7. *Describe the resources that your RHA dedicates to water quality issues.*
8. *Do you have a dedicated employee for this task? What training does s/he have? If no, what level of training would you say the PHIs/EHOs generally have in this area?*
9. *What is the after hours / weekend response capacity to water quality concerns (in terms of resources, staff, etc.)? How does it work in practice?*
10. *Describe the public health relationship with water systems professionals in your region. How often do you need to consult with them?*
11. *What kind of problems does the public health agency encounter in relation to ensuring drinking water safety?*
12. *What would be your priorities for receiving assistance for dealing with the problems identified above?*

III. Training needs:

13. *What would you consider the key issues to ensure drinking water safety? Please elaborate ...*
14. *What would you regard as the major aspects that public health professionals need to know in order to be assured that drinking water is safe for the public? Please be specific in terms of water treatment process, water safety barriers, water monitoring, disease surveillance, etc.*
15. *Which of these aspects would you regard as requiring more focus for public health training?*
16. *What approach would you suggest in order to accomplish these training needs?*
17. *What are the most critical constraints that you face in pursuing these?*

The topics and time allotted for the interview were designed to allow flexibility for more detailed probing around each topic. The interview covered three areas of interest: roles and responsibilities for drinking water safety, approaches to ensure drinking water safety, and training needs of public health professionals.

2.1.3. Interview design

In order to encourage and maintain participation in the interviews, we designed the interview to be completed in about 1 hour, including probing around each topic. The 17 questions were designed to ensure that no major issues are left out of discussion, yet allowing for enough flexibility depending on the specifics of work in each institution visited.

All prospective interviewees received a 1-page information letter (Appendix A), the consent form (Appendix B), and interview questions (Box 1). The research proposal was also provided upon request as additional information on the study. The information letter contained a short presentation of the study, a description of the interview purpose and process, information on analysis of responses, projected results, confidentiality commitment, as well as contact information for the investigators and for HREB.

A draft of interview questions was sent for feedback to three members of the public health profession in Alberta that fit the profile of future interviewees and to a faculty member of the Department of Public Health Sciences at the University of Alberta who specialized in qualitative research.

2.1.4. Interview administration and response

I interviewed medical officers and environmental health managers or experienced PHIs in water safety from 19 public health agencies, 15 in Canada and four in Australia. The interview was administered to a total of 36 interviewees, 26 from Canada and 10 from Australia. Because some of the MOHs specifically requested to have a joint interview with their employees, I conducted 21 interviews in Canada and 6 interviews in Australia. Formal written consent was obtained from all interviewees before the interview took place.

A breakdown of the location and professional profile of interviewees is presented below in Table 1. PHIs interviewed were either water specialists for their team or senior inspectors with many years of experience in water safety.

Table 1 – Profile and location of professionals interviewed

	Alberta	**British Columbia**	**Ontario**	**Quebec**	**Saskatchewan**	**Australia**	**Total**
MOHs	8	1	1	1	1	3	**15**
EHMs	5	1	1	1	1	2	**11**
PHIs	2	1	-	2	-	5	**10**

2.2. Questionnaire survey

2.2.1. Questionnaire target group

The questionnaire survey was designed to supplement the information provided by the interview survey, by allowing a structured inquiry into the knowledge and perceived needs of the public health inspectors / environmental health officers in Canada.

Due to the design of the study at the time of distributing the questionnaire, we only targeted PHIs in Western Canada (British Columbia, Alberta and Saskatchewan). The questionnaire was mailed to all practising PHIs in the three above mentioned provinces. While we used the best available contact data at the time of the project initiation, some currently practising professionals may have not been included in the questionnaire mailing, due to either changing their position or location of work recently, or being fresh graduates starting work after the launch of the study.

The first study objective was to characterise current practices among public health professionals across Canada and not to generate a comparison of results between provinces. Therefore, the survey was purposefully designed to not allow investigators to identify any particular questionnaire response with practising in a particular province. In fact, it is quite common for environmental health officers in one province to look for a better position in a public health agency from the neighbouring province.

2.2.2. Questionnaire content

The questionnaire survey was based on a structured questionnaire containing 14 questions, some open-ended and some close-ended (see below). The purpose of the questionnaire was two-fold: on one hand, to understand current role in safe water and perceived training needs, and on the other hand, to assess the background understanding these professionals would apply when using evidence to guide their risk management decisions.

The questions in the second part of the questionnaire were developed with the underlying assumption that PHI competence in interpreting total and fecal coliform, and HPC results is satisfactory for all practitioners; I thus focused on more subtle aspects pertaining to data interpretation.

The questionnaire consisted of two main parts, plus one question on current position (question 1) and one question allowing for respondent comments on any issues related to the survey (question 14). See Box 2 for questionnaire topics.

Box 2 - Questionnaire topics

1. What is (are) your current position(s) / title(s) [without identifying yourself]?
Please provide your job title only: ______________________________

A. Summary of responsibilities regarding safe water and perceived training needs (questions 2-7)

2. What would you consider to be the role and responsibilities of public health in ensuring safety of drinking water in your region?
Comments on this question:

3. How is this accomplished in practice? Please list specific actions:
Comments on this question:

4. How often do you have to respond to public inquiries on drinking water safety?
☐ *over 20 times /year*
☐ *10-20 times /year*
☐ *5-10 times / year*
☐ *1-4 times / year*
☐ *Never*
Comments on this question or your reasons for selecting your answer:

5. What are the most common concerns?
Comments on this question:

6. Personally, what would you regard as the most important concern for drinking water safety nowadays?
☐ *presence of chemical contaminants (natural or man-made; please specify examples below)*
☐ *presence of biological pathogens*
☐ *taste and odour complaints*
☐ *presence of chlorination by-products*
☐ *presence of other water treatment by-products*
☐ *other (please specify):* ______________________________
Comments on this question or your reasons for selecting your answer:

7. In your opinion, which of the following drinking water related topics should be a part of PHIs / EHOs' training?
☐ *water treatment basics*
☐ *the multiple barrier approach*
☐ *water quality monitoring*
☐ *risk assessment for drinking water systems (e.g. sanitary surveys)*
☐ *risk management approaches for drinking water*
☐ *other (please specify):* ______________________________
Comments on this question or your reasons for selecting your answer:

B. Evidence-based risk management survey (questions 8-13).

8. From your perspective, what do you believe to be the source of most errors in public health risk management actions regarding environmental contaminants in drinking water [choose only one]:
- ☐ *errors in sample collection*
- ☐ *errors in analytical technique and lab procedures*
- ☐ *errors in data interpretation*
- ☐ *errors in the decision-making process*

Comments on question 8. (see previous page) or your reasons for selecting your answer:

9. What is the ***lowest*** *accuracy that you would accept from an analytical method, for a specific environmental contaminant, before you would be confident in taking a major risk management action (e.g. issuing a boil water advisory) based on this method indicating the presence of that environmental contaminant?*

☐ 50% ☐ 70% ☐ 90% ☐ 95% ☐ 99%

Comments on this question or your reasons for selecting your answer:

10. What is the lowest accuracy that you would accept from an analytical method, for a specific environmental contaminant, before you would be confident in not taking a major risk management action (e.g. not issuing a boil water advisory) based on this method indicating the absence of that environmental contaminant?

☐ 50% ☐ 70% ☐ 90% ☐ 95% ☐ 99%

Comments on this question or your reasons for selecting your answer:

11. [A hypothetical scenario] Evidence for a Canadian city has indicated that in treated drinking water, a pathogen, say 'Giardia', is truly present above the recognized standard methods detection limit, about once in every 10,000 water samples from the treated water distribution system.

Assume the analytical test for the pathogen has the following characteristics:
- *99.9% of tests will be positive for detection when the agent is truly present above the detection limit, and*
- *98% of tests will be negative for detection when the agent is truly not present above the detection limit.*

With these characteristics, given a positive result (detection) on the analytical test for the specified pathogen in the Canadian city, how likely do you think this positive result is true?

Provide either a probability estimate __ or indicate your scale of agreement below:

- ☐ *Almost certain (95 to 100%)*
- ☐ *Very likely (80 to 95%)*
- ☐ *More likely than not (50 to 80 %)*
- ☐ *Less likely than not (20 to 50%)*
- ☐ *Very unlikely (5 to 20%)*
- ☐ *Extremely unlikely (0 to 5%)*
- ☐ *No idea*

Comments on question 11. (see previous page) or your reasons for selecting your answer:

12. For the circumstances of question 11, if you have any remaining concerns about this evidence, how would you improve certainty for this result?

13. Does the Precautionary Principle influence your risk management decision-making?
☐ *Yes* ☐ *No* ☐ *Not sure*
Please also state what you believe the Precautionary Principle means:

14. Your comments on any related issues:

The actual questionnaire is presented in Appendix C.

2.2.3. Questionnaire survey design

In order to encourage a high rate of responses, we sought to limit the completion time for the questionnaire to about 10-15 minutes. Because of the time constraint, we limited the number and complexity of questions to 14 short questions, including position identification and comments.

Respondents were provided with a 1-page questionnaire survey information letter (Appendix D). The letter provided information on the research study, purpose of the questionnaire, completion and return instructions, contact information for the study and contact information for the HREB, in case participants may have any concerns.

2.2.4. Questionnaire administration and response

The questionnaire was administered to the practising public health inspectors / environmental health officers in the regional public health agencies of British Columbia, Alberta and Saskatchewan. The questionnaire was sent to a total of 444 inspectors, in two rounds: initial and with a reminder letter. In total we had 146 respondents to the questionnaire, providing an overall response rate of 33%. Anonymity of responses was maintained by having the administrative assistant permanently removing the number used for tracking responses before investigators would see any responses.

3. RESULTS AND DISCUSSION

A summary of the empirical results of the research is provided below, broken down for each method used question by question. Answers are generally organized on common themes and, where relevant, from the most frequent to the least, unless otherwise specified.

3.1. Interview survey summary

3.1.1. Surveyed population

I contacted a total of 40 public health professionals from Canada and Australia. I interviewed 36 of the professionals contacted (27 interviews in total, out of which eight were joint interviews). Although none of them actually explicitly declined participation, four professionals did not eventually respond with a definite offer to our repeated interview requests and none provided a reason for this. The above number of interviewees was estimated to have reached practical saturation for the research objectives.

The interviews generally lasted a bit longer than originally anticipated (about 1 ½ hour on average), partly because more probing was sometimes needed to understand certain topics, and partly because a general introduction into the background and purpose of the study was often necessary.

Most of the professionals interviewed saluted the initiative and expressed interest in the outcome of the study. In addition, some interviewees also volunteered for participation in an advisory group on future training, based on the results of this study.

3.1.2. Summary of responses

The following represents a question by question summary of the actual responses of interview participants in this study.

Question 1:
What are the major public health issues that the public health agency has to address in your region?

Altogether, disease surveillance and outbreak investigations, immunizations, chronic disease prevention and lifestyle issues, certain notifiable infectious disease (e.g. STDs, TB), and injury prevention takes on average between 50-90% of the total full time equivalents (FTE) for a public health unit. Environmental health as well as other more or less seasonal/ unusual issues take up the rest. The environmental health group, in turn, has to deal with a variety of issues ranging from food and water safety (drinking or recreational), air quality, safe housing, to other minor issues.

It is thus quite obvious from the wide range of responsibilities that a public health agency has, that quite often drinking water safety is not among the most important issues for MOHs. Some exceptions may occur though, for example in smaller rural RHAs. As for the environmental health department and more specifically for EHOs, water safety may or may not be a major concern, depending on the district they cover. Rural areas tend to require quite a large time commitment for water safety, sometimes up to 50% of the time. By comparison, urban EHOs not specialized in water safety, working in other areas (e.g. food safety, safe housing), would rarely need to intervene (this is not to say that a working understanding is not desirable, since they may change positions and/or responsibilities, or may have to deal with a water safety issue when no specialist is available, e.g. after hours on call duty).

Question 2:
How would you define the role of the public health agency in regards to ensuring drinking water safety. Please describe specific responsibilities that you understand for this role.

In all provinces and Australian states included in our study, the Health Protection Act (or equivalent) does not normally have specific water safety provisions for public health authorities. Some provinces or states have adopted specific acts addressing the supply of safe drinking water (e.g. Drinking Water Protection Act in British Columbia; Safe Drinking Water Act in Ontario; Safe Drinking Water Act in Victoria, Australia). Other provinces and states rely on general provisions of the Public Health Act and its regulations, and sometimes also on more specific best practice or reference documents.

Interviewees generally defined their role as protecting public health from water related disease. However, understanding of specific responsibilities varies widely. At a minimum, the public health role in some areas was to follow-up on adverse water results (i.e. coliforms present in treated water) and investigate water quality complaints that may suggest potential health risk (e.g. turbidity). However, the largest involvement of public health authorities included supporting a complete source to tap approach, i.e. involve in watershed management; assure source protection, adequate water treatment and disinfection, maintain water quality in the distribution; ensure regular water quality monitoring and follow-up. In areas where public health did not have a specific mandate to be proactive, they had a consultative role, were involved in stakeholders committees for safe water, and provided public education.

Lack of resources and staff, and of specific safe water legislation were usually cited as major limitations to being proactive. Customarily, public health was more involved with small systems, whereas large systems would only be contacted in case of major events (e.g. suspected waterborne outbreak, positive coliform tests, high turbidity, water quality complaints). However, even with small systems public health authorities rarely had a consistently proactive approach (often random or reactive).

Question 3:
What actions do you take to ensure the safety of drinking water in your region?

Actions taken by public health authorities to assure safe drinking water in their area depend largely on the presence of specific safe water legislation.

In the absence of specific safe water legislation, public health would be governed by more general provisions of the Public Health Act. In general, public health would be more actively involved with small systems, and have a more consultative role for municipal systems. While practices vary across Canada, most public health professionals would:

1. Facilitate submission of water samples from small and private water systems to accredited labs;
2. Follow-up on adverse water results: interpretation, investigate cause, advise on solutions to correct (alternative water sources, treatment options);
3. Perform occasional spot checking, the PHI collecting samples directly (for coliforms, turbidity); where there is a concern, water samples may be collected also for other non-routine analyses (chemicals, metals); where field kits are available, PHIs may also perform on-site testing of chlorine residual, pH, etc. ;
4. Investigate water quality complaints that present safety concerns;
5. Perform site visits / inspections, usually targeted by positive coliform results or suspicion of contamination.
6. Educate the public on safe water practices, usually for private well owners (campaigns, pamphlets);

Public health is usually responsible to issue boil water or do not drink advisories/ orders when there are concerns about drinking water safety. They also have a consultative role for other agencies and water operators on health risk and safety issues.

Some regional health authorities (RHAs) with more resources try to be more proactive, even in the absence of legislation. They would often develop inventories of water systems to keep track of water testing results, current state of system and upgrades; involve in risk assessments and development of risk management plans for municipal and small water systems; get more involved in the investigation of municipal water issues along with the Department of Environment; advocate for watershed protection; involve in emergency planning for water systems; and other related initiatives.

Where specific legislation is present, the safe water act would have more specific provisions, which may vary from province to province. In general, in addition to the above actions, public health authorities would:

1. Maintain an inventory of water systems and of adverse results (done in Australia, in process to be completed in B.C. and in some parts of Alberta and Ontario);
2. Be involved in all aspects of safe water provision (in B.C.), in a source to tap approach, including watershed management;
3. Ensure regular water quality monitoring according to schedule and follow-up on adverse results;
4. Be involved or organize (in B.C.) water operator training and certification.

Question 4:
How often do you need to answer inquiries about drinking water safety?

Public health agencies are always involved in addressing public concerns on the safety of their drinking water. According to several interviewees, while citizens may also choose to contact directly their water provider, or sometimes the regulatory agency (which most often is the local office of the Ministry of Environment), in the eyes of the public the public health agency is often highly regarded as the most competent and reliable source of unbiased information for their water safety concerns. This observation of interviewees is supported by the study of Wanke et al. (1996).

Most rural PHIs and PHI water specialists would respond to drinking water inquiries at least on a daily basis. Environmental health managers and city PHIs address water quality concerns less often, depending on expertise and circumstances; on average on a weekly basis.

MOHs have much more diverse responsibilities and would normally rely on their environmental health staff to address concerns. MOHs may get involved on a monthly basis, except for particularly busy seasons (e.g. spring), that requires more boil water advisories (BWAs).

Question 5:
What are the most common concerns?

Public concerns are often driven by water quality parameters tested or by suspected contamination of water supply due to proximity with agricultural or industrial developments. Therefore, most concerns are related to the adverse bacteriological results for treated water samples (presence of coliforms). Concerns often come from the system owner (for private or small non-municipal systems) or from the public (for municipal systems). Questions would relate to coliform test result interpretation and significance, how to correct the problem (often looking for a quick fix to the problem), and how to protect their health.

Other drinking water safety concerns would be related to water aesthetics (taste, odour, turbidity, discoloration), illness of suspected waterborne source (e.g. Giardiasis), significance and duration of a BWA, water sampling procedures (how to, what), system maintenance advice (including tanks), effects of agricultural or industrial developments on water source, and other related issues.

Public concerns may also be generated by various pathogens/chemicals that are present or suspected to be present in the drinking water, such as: THMs and other DBPs, protozoa (*Giardia*, *Cryptosporidium*), naturally or artificially occurring chemicals (arsenic, lead, nitrates/nitrites, selenium, fluoride, barium, sulphates), *Helicobacter pylori (H. pylori)*, algae (blue-green, other algae, algal toxins), pesticides, pharmaceuticals (antibiotics, hormones), hormone-like compounds/pollutants.

Less often, some regional-specific concerns may relate to possible sour gas, hydrocarbons, or sulphates contamination of the water supply. In Australia, in addition to the above, there would be health concerns about wastewater reuse for agricultural or domestic purposes.

Question 6:
Who responds to potential concerns about drinking water safety?

Many concerns are communicated directly to the field PHI during follow-up on adverse results, inspections or outreach activities. These most often relate to interpretation of coliform test results and water system solutions to avoid positive tests in the future. Also, public calling in during business hours are normally referred to the district PHI or equivalent.

Questions that require more specific expertise may be referred to another PHI team member who possesses that expertise, such as a water specialist (e.g. less usual contaminants, such as protozoa, chemicals). Alternatively, the issue may be referred to the environmental health manager if that expertise is required.

Questions referred to the MOH usually come from physicians, but can also be from the public, other agencies or media if it either involves potential health effects, has large public implications or an official authority position is requested. In some regions, the MOH may be the only on call staff available after hours and on weekends.

Question 7:
Describe the resources that your RHA dedicates to water quality issues.

Resources dedicated by a RHA to water quality issues largely depends on the existence of specific water safety legislation and the overall resources dedicated to public health or environmental health. Dedicated resources are also influenced by need (N.B. but it depends how they identify and define 'need').

In terms of full time equivalents (FTE), most commonly 0.5 FTE are estimated to be spent on water safety by a public health agency. The estimate is higher for larger RHAs, up to 2.5 FTE. In B.C., where public health is directly responsible for drinking water, it can go as high as 5 FTE for a large RHA. Water safety specialized staff may be present in different forms, as it is described in the answer to the next question.

Question 8:
Do you have a dedicated employee for this task? What training does s/he have? If no, what level of training would you say the PHIs/EHOs generally have in this area?

The presence of public health employees dedicated to water safety issues depends on resources and priorities (or vice versa, since priorities may influence resource allocation). Their existence also apparently depends on the size of the region; however, when asked, most interviewees would actually see the need and scope for a dedicated full-time staff.

In general, large RHAs would have dedicated water consultants within their environmental health team. Other RHAs may have water specialists, which usually are a PHI/EHO specialized in water safety, but with regular EHO responsibilities. Such a specialist would normally be the water safety resource person on the team, and assist its co-workers where more specific knowledge is required (test result interpretation for unclear results, unusual contaminants; advice on newer water treatment options, etc.). Yet other RHAs would not have any specialized person, but would rely on peer consultation and the support of senior PHIs.

PHI/EHO training usually consists in environmental health degree/diploma, practicum and on-the-job training, plus attendance of specific drinking water related workshops and conferences organized by professional associations (e.g. CIPHI) or other agencies (e.g. Environment). Workshop attendance largely varies depending on local opportunities and/or RHA support for such training.

Question 9:
What is the after hours / weekend response capacity to water quality concerns (in terms of resources, staff, etc.)? How does it work in practice?

All interviewees have reported having some form of after hours public health/ environmental health response line or paging system that can be used by public and other agencies to communicate water safety concerns. The form however varies across provinces and states. The response line is normally available to other professionals, agencies, or municipal water operators. The general public may or may not have direct access; in some cases, there is a centralized emergency number, where the operator will in turn call the secondary environmental health line. Reportedly, the after hours response capacity in many public health agencies has been improved following the Walkerton tragedy.

Some regions may only have the MOH on call to answer to all public health issues. In other regions, a PHI/EHO or a public health nurse would also be on call (by rotation). The person on call will usually follow a pre-established adverse water results protocol; if s/he estimates that situation requires this, will call a PHI to investigate the causes and advise corrections and public health action (e.g. BWA if necessary). Depending on the region/province, such scenarios may or may not have happened in practice since the introduction of the emergency response lines.

Question 10:
Describe the public health relationship with water systems professionals in your region. How often do you need to consult with them?

The public health relationship with water systems professionals in their region varies widely, depending on public health mandate regarding drinking water systems in the respective province.

In British Columbia, public health agencies hire their own public health engineers and drinking water officers, who license and inspect water systems, and train water operators. Public health agencies have thus a very close relationship with water professionals.

At the opposite spectrum in this regard, in Quebec public health has more of a consultative role for drinking water. Here, it is the Ministry of Environment who licenses, inspects and trains water operators. Public health has no direct contact with water operators except in extreme circumstances. In case of adverse results, most drinking water quality and safety issues are resolved directly by the Ministry of Environment officers.

In Alberta and most other provinces (as well as in New South Wales, Australia) the Department of Environment licenses municipal systems and systems over a certain size (e.g. over 5-15 connections, over 4000 gallons/day, etc., depending on province). The summary below refers to these provinces, unless otherwise specified.

Public health relation with municipal drinking water systems or Department of Environment mostly consists of two-way communication on problems that potentially may impact water safety (e.g. chlorination not working, filtration inefficient, cannot control turbidity) and to discuss the opportunity for public health advisories (BWA, do not drink advisory). Other water safety concerns may be discussed, if Environment sees a need for public health input, but there is not legislation to require or formalize this input. A public health professional's involvement as consultant for other public health risks will depend on individual expertise. Many interviewees have expressed a willingness to develop and maintain partnerships with drinking water regulatory agencies. This sometimes takes the form of local drinking water committees.

In these provinces, public health is not consistently involved in licensing and license renewal for regulated drinking water systems. The public health agency may sometimes be asked for opinion if issues with a water system relates directly to public health concerns. Other than that, district PHIs may occasionally collect some grab samples of treated water by themselves and have them tested; more of a check-up for municipal systems. A few interviewees have expressed doubts on the current capability of regulatory agencies to assure drinking water safety for small regulated drinking water systems. This has been explained as a combination of the agencies being resource strained, of having priorities that may differ from those of the public health unit, and of communities having limited funding for system upgrades.

In most provinces, public health is the agency that is closest in contact with small drinking water systems operators and private systems owners. While not usually mandated specifically by law, public health in effect becomes the default agency responsible for these systems in the interest of safeguarding population health. Also, by default, public health would be responsible for any other systems that are not regulated, transient or non-transient (e.g. fairs, campgrounds, trailer parks, Métis settlements). Therefore, public health's involvement with small systems, depending on resources and staff, may consist of field inspections, facilitation of sample analysis and interpretation of results, and advice on corrective actions. One of the most positive observations during my interviews was that public health staff by and large is beginning to recognize the need for partnership, and quite often the management itself encourages them to maintain a mutual respect relationship with water operators.

In terms of contact with water system professionals, large RHAs, usually including one large city, would have resources to hire dedicated PHI water consultants that stay in regular contact with municipal water system staff (e.g. Edmonton, Calgary). For other RHAs periodic contact with larger municipal systems in their area is common (e.g. weekly to monthly). This usually depends on the personal experience and training of public health staff, but time availability is limited, since they cannot hire a dedicated water safety person.

Question 11:
What kind of problems does the public health agency encounter in relation to ensuring drinking water safety?

Interviewees provided a wide variety of responses to this question. In addition, many important points and relevant stories were given in response to other questions in the interview, whenever the participants felt it useful to explain their point by referring to problem(s) they encountered. Here are the most common themes:

1. Water safety is often regarded as having low priority among public health issues, which is reflected in lack of specialized staff and resources.

This is not necessarily a problem at the level of RHA management; quite often it seems to reflect a more general attitude of the governing bodies, which regard the issue of drinking water provision as a mere technical issue. This gets reflected in fund allocations in the municipal budget for drinking water systems, funds allocated to and within the regulatory agency (i.e. Environment) for licensing and inspection, funds allocated by RHA for environmental health activity and, sometimes, also budget allocation within the environmental health team. This seems to be more an issue of awareness (or lack of it), since several important changes seem to have been implemented following the incidents in Walkerton and North Battleford. This observation can also explain why existing funds are more judiciously allocated to water safety by management levels close to the issues (i.e. public health agency and environmental health team leadership), since they have a better understanding of priorities.

2. Lack of specific safe water legislation.

This is also often explained by participants by the low priority given to drinking water safety at governmental levels. Canadian provinces vary largely in this regard, and so do Australian states. The impact of lack of legislation varies, but to some interviewees this was regarded as a hindrance to effective public protection from unsafe water. However, Alberta for example lacks a separate drinking water act, although the Environmental Protection and Enhancement Act enforced by the environmental agencies has a part devoted to regulation of potable water (AE 1993). Yet here regulatory agencies have already moved towards promoting guidelines of good practice.

3. Small drinking water systems are plagued by numerous issues that impact water safety.

While 'small drinking water systems' may be defined differently in different provinces and states, the quality of drinking water provided by these systems seems to be a general concern to most interviewees. Under this term we have in fact a wide variety of water systems improvised for various purposes. They may serve permanent local residents, such as in small communities (usually under 15-20 connections), private developments who were designed with their own water system, or trailer parks (a "temporarily-permanent" population). Others may serve a non-resident population all-year round such as schools, office buildings, factories, other industrial development, etc. Yet others may serve a transient population, such as motels, restaurants, national parks and churches.

Municipal systems, serving large numbers of people residing locally, were always the first target for any measures to improve drinking water safety. They also benefit from a low cost per capita of drinking water, which allows them resources to hire trained professionals and receive more expertise. Unfortunately, this seems to have encouraged also a tendency for these systems to become almost the only ones that do get attention. Shortage of funds is often cited as the primary cause for limitations of the small systems. In most, if not all regions visited, it seems that PHIs are the main source of advice on water safety issues for small drinking water system operators, whether regulated or not.

One of the most important issues was the training and competency of operators of small systems. There are generally no expectations at present time for individuals responsible for small unregulated systems to have any formal training, let alone certification. Untrained, insufficiently trained or improperly trained water operators probably represent the most underestimated source of concern by governmental regulators. In addition, it seems that in some provinces public health has very limited input in water operator training. This is understandably a consequence of safe drinking water provision been regarded as a technical, not a public health issue.

Funding of small water systems was another reported constraint. Many interviewees cited costs as being, in their opinion, a major restriction to bringing these systems up to current standards of safety. However, it is important to note that the relative cost of water, an essential need for healthy living, is in fact a very low cost in the overall budget of a household (usually tens of dollars per month, depending on the area). Merely doubling the cost to add important preventive measures in the system would be a very small price to pay for such an important commodity.

Awareness to water safety issues was likely the most critical aspect revealed explaining the current status of small systems. Lack of awareness leads to indifference and, sometimes, resistance to improving water safety and it is also a major deterrent of any initiatives where only the cost seems to matter, since no real value is placed on the advantages of upgrading the system. Some public health agencies organize targeted awareness campaigns to address the issues, but often funding is limited to support such initiatives.

4. Many drinking water systems do not have enough funding.

This aspect was referred to in relation to the small water systems. However, funding for system upgrade (water treatment, disinfection, maintenance, water source re-location, distribution system integrity, cross-connection avoidance, etc.) and operator training and certification is, in some provinces and locations, sometimes an issue for larger water systems as well.

5. Seasonal variations in raw water volume and quality, as well as water source sustainability, presents serious challenges for the future.

Seasonal variations in water source quantity and quality may lead to serious challenges to the drinking water systems (e.g. drought, spring runoff, algal bloom development). In addition, in some regions there are concerns regarding the sustainability of water source. On average such issues seem to affect more Australian states than any Canadian province. However, it is still an important concern in some areas in Canada (e.g. Southern Alberta), and it may be even more so in the future. As the population grows, accommodating residential, industrial and agricultural development requires careful planning, foresight, and, sometimes, difficult decisions in order to preserve sustainability. In fact, the Australian experience in this field could well benefit Canadians, since Australian states have, so far, been quite successful in managing their water source challenges and they are learning useful lessons that we could follow.

6. Various sources of watershed and water source contamination.

The interview notes indicate that public health, environmental and water professionals recognize increasing sources of contamination and types of contaminants, which can affect water safety at various stages in the source to consumer continuum. Watershed and source water contamination concerns referred to: natural chemical contamination, particularly for groundwater sources (e.g. arsenic, boron, selenium, barium, fluoride, and other); agricultural developments: manure (biological contamination), nitrates, pesticides, water body eutrophication (fertilizers), etc.; industry (e.g. trichloroethylene, lead, hydrocarbons); other developments that may produce oil or fuel spills (e.g. oil and gas, forestry). Human and animal fecal contamination is the most common form of contamination and may occur at various stages in the drinking water production, due to release in the watershed/water source, sewage systems leaking or too close to water source, cross-connections, and other related causes.

Most interviewees also recognized increasing challenges in providing expertise, result interpretation and support to public and other stakeholders as it relates to the health risk that a water contaminant poses to the public. The challenge is not easy. Public health has to deal not only with the scientific, but with social, economical and, sometimes, political implications of their decisions. This is no news for public health authorities, since they are faced with such implications in other areas as well, and not just for water safety. The added difficulty here, however, is that when it comes to health risk of chemical contaminants, even science is uncertain. For most of them, science may not have a definite answer whether they are truly a health risk at ordinary levels in drinking water.

Fortunately, the aspects of biological contamination of drinking water are better established than for chemical contaminants. There is a general consensus on the health risks for common pathogenic organisms in water given our unfortunate experience with waterborne epidemics. The challenges here relate more to preventing contamination at various levels in the drinking water provision process. Concerns were expressed for the fact that often public health has limited control over watershed developments that may impact water safety.

7. Old water treatment and distribution systems.

Another major concern for drinking water safety was old water treatment equipment, not very effective against new and emerging pathogens (e.g. protozoa), as well as aging distribution infrastructure, with infiltrations and cross-connections. Drinking water systems may often lack resources to upgrade, but improving water quality is also a low-priority for many consumers.

This was mentioned as another major concern for drinking water safety at various points. Some water systems were designed and built decades ago, and never really upgraded. Not only the water treatment is antiquated, but often they were not designed to be completely protected against sewage contamination. At the same time, population they serve increased, sources of contamination multiplied and new pathogens challenge the treatment they provide.

The most typical example provided was *Cryptosporidium*, for which only a combination of watershed protection, continuous effective filtration (minimum 3-log reduction), effective disinfection like ultraviolet radiation (UV), and an intact distribution system can ensure adequate protection. This is a challenge for all water systems who, at any time, may provide an incomplete filtration process, are often contaminated with sewage, only use chlorine disinfection or present cross-connections with sewage systems in the distribution. In the opinion of most interviewees, many small and medium size water systems qualify in this category. This in effect makes such systems potential sources for a *Cryptosporidium* infection outbreak waiting for an opportunity to happen.

8. Other issues:

Interviewees also referred to other issues that may be grouped under the heading of public and institutional awareness. Among them is availability of water testing for private and/or small system owners. Some provinces offer the service free of charge (and EHOs actively facilitate the process for high-risk systems), others do not.

Water systems that are under recurring or ongoing BWAs (sometimes for years) due to frequently positive coliform results are an ongoing concern in some areas. The manner in which such issues are dealt with varies from one area to another: sometimes the municipality would organize an alternative drinking water supply (e.g. tanked water), other times there would be no intervention, due to a common belief that the water is still fine. Regardless of the approach, the community involved is not provided with a sustainable safe drinking water supply. This not only presents a permanent health risk, for inadvertent drinking of unsafe water would still occur (children, tourists, etc.), but it promotes a double standard of living in Canada. Access to safe drinking water is part of our standard of living. In addition, the cost-effectiveness of such approaches has been discussed above in this section.

Difficulties were also reported in relation to investigating water system problems in special jurisdictions, such as industrial developments or aboriginal reserves (when they share the same water system with or in other ways influence drinking water quality for areas outside the reserves).

Lack of expertise for consultation was mentioned by several interviewees and it relates quite often to the ability to evaluate and explain to the public and other stakeholders the health risks of more unusual chemical or biological contamination of raw or drinking water (e.g. algal toxins, various chemical hazards). The same goes for advice on specific water treatment aspects related to such contamination (e.g. efficiency of current system barriers to reduce/eliminate health risks associated with specific contamination).

Question 12:
What would be your priorities for receiving assistance for dealing with the problems identified above?

In this section I listed the most important priorities for assistance in the view of professionals interviewed, with the exception of training needs, which are addressed in the next section.

1. Additional staff and resources.
With some notable exceptions, most interviewees estimated that properly addressing water safety issues in their region would require more manpower and resources than they currently have. Resources referred primarily to funding, training and field equipment. There was also generally an agreement that funding should be provided to afford having a dedicated full-time water consultant for the environmental health team.

2. Training and access to training.
This topic is addressed in more detail in the next section. Professionals in some regions felt that they should have better funding to improve access to training, whereas others estimated that their training budget is sufficient.

3. Jurisdiction and communication between stakeholders.
Some of the interviewees considered that there is not a clear definition of jurisdiction and responsibilities for various stakeholders in the field of water safety. In practice, there may be either overlapping, or more important, some areas will "fall in the cracks" of jurisdiction (e.g. small systems where the actual number of connections is debatable, Métis communities, provincial parks, etc.).

Overlapping is generally resolved quite easily to public benefit by setting up a committee, where various stakeholders are represented.

Unclear jurisdiction is more serious, because of lack of resources that can be dedicated to the issue and because enforcement may be difficult. In this respect, public health agencies seem to be quite often placed in the position to be the "default" responsible for "grey areas", because of their overall mandate to protect public health. Such situations often add unfair strain to their limited resources and are difficult to address completely, since they have no clear mandate. Often the result is that such issues are addressed only reactively, solutions are often incomplete or the situation may be only partially resolved. One example is placing indefinite BWAs for consumers, without planning and implementing long-term improvements of the system.

4. Free water testing for all small systems, private or public.
Some interviewees expressed a view that free water testing in every province would benefit public health. The issue was referred to in relation to lack of funding for small water systems, municipal, communal or private. Some provinces have already moved towards offering free water testing for private water systems, while other may have offered it in the past but dropped it. However, this disregards the fact that safe water is not cheap, and someone has to pay to assure the safety of your drinking water supply. A province may afford to support a free testing program for small systems in order to assist public health efforts, but externalizing costs may not necessarily be a sustainable solution.

5. Resource persons and the need for expertise.
This was also mentioned in the previous section. Co-operation and personal contact with universities and other resource centres (like B.C. Center for Disease Control, or Quebec National Public Health Institute) is often used to address the need for more specific information on less routine issues. It may however be even better to build some form of internal expertise capacity dedicated specifically and readily available to public health field professionals. Some Australian states (VIC and NSW) have set up water safety units/ programs that provide specific consultancy to stakeholders and promote legislation in this field. In B.C., every RHA now is developing its own drinking water officers to serve as an information resource.

6. Water systems inventory.
This initiative has been started in several areas, sometimes also concurrent with a risk assessment process for these systems. It is obviously a necessary step to any strategy to improve water safety. The best way to optimize the use of such a resource will eventually be to develop system-specific risk management plans that will need to be followed by every water system, with water results data being used as the confirmatory rather than the sole check-up measure.

7. Promotion of safe water and related legislation.
Some interviewees considered that most reported problems would likely be resolved by the adoption and implementation of a safe water act in provinces and states where it does not exist. Sewage regulations should also be tightened where it has not been done yet to consider protecting drinking water sources. Legislation should also include watershed protection as a public health measure (rather than just environmental related).

Question 13:
What would you consider the key issues to ensure drinking water safety? Please elaborate...

Interviewees provided a wide range of responses to this question. I organized their responses on common themes below, in the order of importance and frequency of responses:

The most common key issue was the importance of water operator training that is consistent and adjusted to expectations to perform (i.e. specific training for small drinking water systems). It was noted that sometimes small water system operators may take training that prepares them for large system requirements, instead of improving their understanding of the system they are managing. In this respect, many interviewees advised the need for a formal requirement of training and possibly certification for all operators that respond for a public water system, regardless of its size and whether it is regulated or not. Training for small system operators could be done by either Department of Environment or PHIs.

The next common theme was that all public health professionals, including water operators, must have a good understanding of water monitoring and significance of results. Related to this, was the implementation of an effective and consistent drinking water monitoring program and development of more detailed protocols on how to treat adverse results. However, no interviewee seemed to clearly understand that current major reliance on water monitoring for prevention is neither cost efficient nor very effective (particularly for small systems).

Some more informed interviewees also referred to a source to tap approach to drinking water safety as a key issue to assure safe drinking water. This should include a multiple barrier approach to prevention and protection. Related to this, some interviewees warned of the need to empower public health to have a real say on watershed developments that may impact water quality. Development of emergency response and contingency plans for drinking water systems was also advised in preparation to cope with unusual events.

Public education on safe drinking water was also mentioned. This referred mostly to private well and small system owners that should understand water safety risks and take appropriate action (safety barriers, water testing), but also to seasonal users of small systems (e.g. campgrounds, summer cottages). Education campaigns should advise them to use adequate water sources, or consider water regionalisation when local resources are insufficient or no adequate water source is available.

Some interviewees also felt that there is a need for more information resources for public health on various aspects of drinking water safety.

Question 14:
What would you regard as the major aspects that public health professionals need to know in order to be assured that drinking water is safe for the public? Please be specific in terms of water treatment process, water safety barriers, water monitoring, disease surveillance, etc.

Interviewees provided answers based both on their training and work experience. Some of the recommendations for public health training repeated answers to the previous question regarding key issues. The question did not refer to whether the topics may or may not be in the current school curriculum, but rather sought to get a comprehensive list of most important drinking water safety topics for future public health training. The topics have been organized in the relative order of importance as seen by interviewees.

PHIs have to understand aspects of water system infrastructure and process relevant to water safety. Good knowledge of the new water treatment technologies (UV, ozonation, membrane filtration) and their advantages and limitations for drinking water treatment is necessary. Also, they have to understand that water safety is a multi-step process and the need for multiple safety barriers, i.e. the purpose of each barrier, that each step is 100% needed, the purpose of using multiple barriers for the same goal (e.g. achieving effective disinfection by using both chlorination and UV), and related issues.

Understand water system monitoring and significance of results for consumer health (including significance of operational indicators of barrier failure). Be competent to interpret drinking water quality monitoring results not just for bacteria, but for emerging pathogens as well (protozoa, viruses). Understand different waterborne pathogens, specific removal aspects and significance of their presence in treated water (e.g. *Cryptosporidium*).

Be able to perform source to tap risk assessments for both large and small water systems; understand ecology issues that may impact water safety (e.g. runoff, eutrophication). Be able to develop risk management plans for a water system (either large or small or both, depending on needs).

Some interviewees also advised on the need for all public health professionals to develop specific waterborne outbreak investigation skills. Quite often waterborne outbreaks are identified too late, usually by exclusion (i.e. not a foodborne outbreak).

Many interviewees emphasized the importance of risk communication skills in various aspects of their work: fieldwork, system inspections, education campaigns, public speaking, and media relations. Risk communication was viewed as an important determinant of the effectiveness of their work to improve drinking water safety.

Other more context-specific training topics were mentioned by a few interviewees: able to perform health risk assessment for various contaminants; develop emergency response and contingency plans; computer skills, use of water systems database; understand water operators' public health training needs.

Question 15:
Which of these aspects would you regard as requiring more focus for public health training?

Answers to this question are organized by professional groups, given their distinct responsibilities.

Public Health Inspectors
Water monitoring was considered to be generally well covered in environmental health school at the present time. Recommendations included: drinking water guidelines and standards, risk assessment and risk management for environmental contaminants in drinking water, risk assessment for drinking water systems, development of risk management plans for a water system, risk communication, water treatment basics and advantages and limitations of new technologies, elements of waste water management (particularly for private sources), recognition and epidemiologic investigation of waterborne outbreaks. These recommendations referred to both student and practising PHIs.

Medical Officers of Health
MOHs do not generally receive specific drinking water safety training in medical school or during their residency program. On the other hand, they are typically involved in many public health areas. Interviewees recommended training in drinking water guidelines and standards, high-level health risk assessment and risk management with case studies and large opportunity for discussion, and updates on water treatment technology and approaches to drinking water safety. Community medicine residents (potential future MOHs) were recommended to receive some specific basic water safety instruction that prepares them for MOH positions (since they do not receive this in medical school): recognition and investigation of waterborne outbreaks, basic water treatment principles, water safety barriers (purpose, advantages and limitations), and risk assessment and development of risk management plans for water systems.

Question 16:
What approach would you suggest in order to accomplish these training needs?

The question referred to the technical aspects of organizing future training for public health professionals. Different training delivery options were all considered acceptable in principle, but will have to be adjusted to circumstances and financial limitations.

General recommendations to courses were to organize them in a user friendly manner, consider competing responsibilities (e.g. short-term, modular, allowing them to take one module at a time); focus on organizing regional or local workshops that would reduce travel costs; invite other stakeholders in local workshops, particularly water operators; involve experienced practitioners (MOHs, PHIs, water operators); include workshops in continuing education credit schemes for MOHs, and for PHIs if such schemes will be set in the future. Other recommendations included to define a provincial standard of minimal knowledge and training in water safety, and to have specialized university courses for more advanced knowledge.

Some interviewees considered that online courses may have limited efficiency, since direct peer-to-peer exchange of experience is much appreciated. In some areas, this may also be limited by the lack of computer infrastructure.

Question 17:
What are the most critical constraints that you face in pursuing these?

The most critical constrain, common to most interviewees, was time availability and competing responsibilities. By the nature of their job, public health professionals have many responsibilities and limited time to address them. Taking time out for training is often difficult and other responsibilities usually take precedence.

Lack of funding was considered a critical constraint in some provinces and some regions, while in other areas this was not considered a problem.

Some interviewees also cited the lack of expert support for consultation or to organize such training.

3.2. Questionnaire survey summary

3.2.1. Surveyed population

We sent the questionnaire to all 444 practicing PHIs/ EHOs in B.C., Alberta and Saskatchewan recorded in our database. 146 professionals responded to the questionnaire, providing a 33% overall response rate. 12 envelopes were returned unopened, which indicates that the addressee did not work in the same place at the time of mailing.

Many respondents saluted the initiative of this survey, being given an opportunity to express their problems, concerns and ideas related to drinking water safety, and expressed their interest to learn of the outcome of this study.

3.2.2. Summary of responses

Overall, the range of responses suggests that this first inquiry into the drinking water safety component of public health work was generally well designed to maximize respondents' input (except question 4, where I apparently underestimated the average frequency of public inquiries on drinking water safety).

Because this was a qualitative study with open-ended questions, I had to use a certain level of personal discretion in classifying the answers, just enough to make the data set manageable.

In regards to the analysis of responses in this questionnaire, since the study was originally conceived as a qualitative study and designed as such, I reported frequencies and percentages only in order to aid qualitative analysis of responses. In general my focus was to detect trends and common beliefs, rather than to provide extensive statistical analysis on questionnaire data, which would contravene the original purpose of the study. For the same reason, optional comments provided by respondents have been characterised only using qualitative terms. Any further statistical analysis of this data set is unwarranted and would only risk providing a false sense of precision.

Question 1. Current position

Out of all 146 respondents, 113 (77.4%) of them identified themselves as PHI/EHO, 6 (4.2%) as Senior PHI/EHO, 9 (6.2%) identified themselves as EH Manager/Coordinator or similar, 3 (2.1%) as PHI students/trainees, 4 (2.7%) as drinking water specialists, and 3 (2.1%) as Senior DWOs. Eight professionals (5.5%) mentioned other positions that to not allow a clear appreciation of the extent of their involvement with water safety issues (Table 2). All responses to this question were included in the analysis (100%). In table 2, 'public health inspector' (PHI) or 'environmental health officer' (EHO) represented distinct self-designated positions by individual respondents. However, from a regulatory point of view they represent the same public health enforcement position in the Canadian public health system.

Table 2 - Current work position of questionnaire respondents

Response category	Frequency	Percent
Communicable Disease EHO	2	1.4
Coordinator EH	1	.7
Drinking Water Protection Specialist	1	.7
EH Manager	1	.7
EH Supervisor	2	1.4
EHO	42	28.8
EHO for community care licensing	1	.7
Enteric Illness Consultant	1	.7
Foodborne Illness Investigator	1	.7
PH Coordinator	1	.7
PH Nurse	1	.7
PHI - Tobacco	1	.7
PHI - Water	1	.7
PHI	71	48.6
PHI / Drinking Water Officer	1	.7
PHI Leader	1	.7
PHI Manager	2	1.4
PHI Supervisor	1	.7
PHI Trainee	2	1.4
Research project coordinator	1	.7
Senior Drinking Water Officer	3	2.1
Senior EHO	1	.7
Senior PHI	5	3.4
Student PHI	1	.7
Water Consultant EHO	1	.7
Total	146	100.0

A. Summary of responsibilities regarding safe water and perceived training needs (questions 2-7)

The purpose of this section was to understand how respondents regard their current role in assuring safe drinking water, the current challenges to doing this for public health and perceived training needs.

Question 2. What would you consider to be the role and responsibilities of public health in ensuring safety of drinking water in your region?

All respondents addressed this question. All 146 responses were included in the analysis (Table 3). The majority of respondents provided multiple answers. The answers are not exclusive to each other, i.e. one respondent may have mentioned more than one type of response. It should be noticed that sometimes the most mundane tasks may have been forgotten, e.g. it is quite likely that virtually all respondents, rather than only 108/146 (74%), follow-up on monitoring results and enforce regulations.

Only 22 respondents (15.1%) have stated in their own words that the public health agency is fully responsible to assure that safe drinking water is delivered to the public. 71 respondents (48.6%) recognized an active role of inspecting facilities (usually non-municipal water systems) and working together with operators to educate them and enforce provision of safe drinking water. As mentioned above 108 (74%) of respondents mentioned ensuring compliance with current regulations, policies and guidelines, by monitoring water quality results (bacteriological and chemical) and following up on adverse results (often by phone calling) – a largely reactive role.

It is of course likely that some respondents did not mention details of their work even though they still perform it, therefore the statistics only give an approximate idea of their activities. However, one can also appreciate that people usually mention what is paramount in their activity, thus, if a respondent sees a primary role as follow-up on adverse bacteriological results, it is likely that this will be mentioned first when thinking about drinking water safety.

The answers to this question also confirm two observations of the interview survey:
1. The main activity regarding drinking water safety for public health professionals who responded is still the follow-up on water monitoring adverse results (usually bacteriological, sometimes turbidity, THMs or chemicals);
2. That public health agencies exert their role to assure safe drinking water by working mainly with small and private water systems, as well as by providing general public education.
To note, most respondents responded by listing specific actions, rather than defining the role.

The comments to this question provided further insight into the issues and concerns that these professionals have. Some respondents considered that public health agencies should have a more active role in approving and overseeing public drinking water systems. At the same time, they expressed doubts about the capacity of environmental bodies to adequately protect population health in this area, due to their limited public health training and understaffing.

Table 3 – The role and responsibilities of public health agencies regarding drinking water safety

Response category:	**Frequency**	**Percent**
To oversee compliance with current regulations and guidelines: review water quality monitoring & enforcement to correct. – mostly reactive role, include all systems (municipal or not)	108	74%
Inspection of public water supplies (including cross-connections, backflow hazards), and work together with water treatment plant operators to prevent, advise, audit, etc. to promote safe drinking water (e.g. education of operators to meet their responsibilities) – more active role, usually for non-municipal systems	71	48.6%
Public education, technical advice, access to testing facilities and results interpretation for those with private water supplies (active promotion of safe drinking water practices)	58	39.7%
To advise the public when consumption of water may be injurious and actions to take (e.g. issue BWAs)	27	18.5%
Public health has the role to ensure that drinking water is safe for the public.	22	15.1%
Review policies and guidelines, and lobby government for safe water	10	6.9%
Monitoring incidence and investigate for possible waterborne disease	9	6.2%
Work with other agencies; supervising / shadowing inspections done by other departments (e.g. Environment)	8	5.5%
To respond to inquiries/ complaints regarding water quality and safety	7	4.8%
License water purveyors and approve water treatment	6	4.1%
Source water protection	5	3.4%
Ensure emergency preparedness	4	2.7%
To regulate small water systems (as defined by provincial legislation)	3	2.1%
Investigation of pollution incidents	3	2.1%
Disease prevention	3	2.1%
Water system risk assessment	3	2.1%
For large water systems, public health should only intervene when bacteriological results are unacceptable	2	1.4%
Ensure staff are knowledgeable of regulations, policies and guidelines	2	1.4%
Keep current on new technologies, developments (e.g. multi-barrier approach)	2	1.4%

Should approve public water systems	1	0.7%
Should be more involved with private water supplies	1	0.7%
Creating a drinking water speciality team who deal directly with this issue	1	0.7%
To identify water systems	1	0.7%

A respondent also estimated they would need a separate department to effectively accomplish all their responsibilities regarding drinking water safety. Other respondents emphasized that small water systems and bottled water require more attention, and that current approaches to not accomplish complete population health protection. Yet other respondents referred to the safe drinking water act as covering all that is needed, and that drinking water safety requires team work.

Question 3. How is this accomplished in practice?

In general, respondents tended to duplicate their answers to the previous question, adding a little bit more detail. While descriptive frequencies of their most common answers (see Table 4) do give some idea of their activity, it is again the comments section that provides more insights into the problems they are confronted with in this field.

Several respondents from urban RHAs (according to their statement in the questionnaire) affirmed that the stated role and responsibilities for previous question are not very well accomplished in practice; they mentioned limited involvement in overseeing municipal water supplies (except for public health advisories), lack of input in the design and installation of new drinking water systems, and field inspections being done only on complaint basis (i.e. reactive).

Respondents also noted the lack of resources and staff to accomplish these responsibilities, recommended again a dedicated water safety department (run by either the environment body or de novo), and affirmed competing interests from other agencies that discourage co-operation (e.g. approving activities that may affect watershed protection) and lack of governmental interest (e.g. to promote groundwater chlorination).

Note:
It may seem like it would have been preferable to use multiple choice, rather than open-ended, questions for questions 2. and 3. This could be a recommendation for future surveys, but at this stage, given that there was no previous research on this topic, I considered important to leave the options open.

Table 4 - Summary of questionnaire responses regarding public health actions to assure drinking water safety

Response category	Frequency	Percent
Monitor public drinking water systems; facilitate sampling and assure monitoring schedule compliance; review lab reports & follow-up on unsatisfactory results (investigation, resample, enforcement); maintain an inventory of results.	101	69.2%
On-site inspection of public water systems, routine or reactive (e.g. sample collection, field testing, field surveys)	74	50.7%
Education, training of water treatment operators and technicians, recommendations for monitoring, maintenance and upgrading	42	28.8%
To advise the public when consumption of water may be injurious and actions to take (e.g. issue BWAs)	31	21.2%
Public education (educational materials, awareness campaigns, etc.)	26	17.8%
Facilitate sampling, results interpretation and advice on correction for owners of private water supplies	22	15.1%
Responding to inquiries/ complaints regarding water quality	21	14.4%
Communication/consultation with stakeholders (operators, labs, Environment, municipality); conduct joint inspections; participate in relevant committees	17	11.6%
Initiate communication with operators (usually telephone)	7	4.8%
Inventory and categorization of water systems; source-to-tap water system risk assessment	6	4.1%
Issue permits for facilities	4	2.7%
Investigate for possible waterborne disease	4	2.7%
Policy development, lobby government for better safe water standards	4	2.7%
Emergency / disaster response	3	2.1%
On-site inspection of private water systems	3	2.1%
Ensure emergency preparedness	3	2.1%
Keep current on new technologies, developments	3	2.1%
License water purveyors	3	2.1%
Create a drinking water speciality team	1	0.7%
Investigation of pollution incidents	1	0.7%
Ensure staff is trained of regulations, policies and guidelines	1	0.7%
Source water protection	1	0.7%
Promote strategic land development practices, i.e. to avoid proliferation of small systems	1	0.7%
Integrated regulatory approach & financial planning for infrastructure replacement / upgrading.	1	0.7%

Question 4. Responding to public inquiries on drinking water safety

This question was intended to assess the extent of respondents' involvement with drinking water safety issues. Responses confirm that the vast majority of respondents, 144 out of 146 (98.6%) are dealing with public inquiries on drinking water safety, which is important for external validity of the survey results.

On the other hand, being in a completely new field of research, I obviously underestimated in the formulation of this question the volume of such inquiries for most PHIs, thus most respondents (93 or 63.7 %) fall into the "over 20 inquiries per year" category. 13 respondents (8.9%) reported 10-20 inquiries per year, 18 respondents (12.3%) reported 5-10 inquiries per year, 20 respondents (13.7%) reported 1-4 inquiries per year and 2 reported never having to respond to public inquiries on drinking water safety (Table 5). All responses to this question were included in the analysis. 55 respondents also provided relevant comments, which are discussed below.

In their comments to this question, many respondents noted that EHO responsible for rural areas handle much more drinking water inquiries than urban EHOs (except for urban water consultants). Respondents in the "over 20 inquiries per year" category generally noted that they handle drinking water safety inquiries almost daily (some up to 15-20 per week). Small residential and non-residential (e.g. campgrounds) drinking water systems represent the bulk of inquiries. Where specialization exists (e.g. dedicated water specialists) assigned staff would handle most of these calls. Respondents in the lower categories were thus either from urban areas or had specialized water staff in their office that take most calls.

According to respondents' comments, many calls refer to water safety complaints and positive coliform test interpretation for private supplies, but also some general inquiries (e.g. water supply). Water safety issues seem to be more common in rural areas, whereas in urban areas would be more about water aesthetics and seeking assurance on safety. In an area with many boil water advisories, most calls were related to explaining their meaning and actions to the public (particularly new arrivals). One respondent also remarked that should the public be more aware of drinking water safety issues, they would ask more questions about both private and public water supplies.

Table 5 - Frequency of public inquiries on drinking water safety

Response categories:	**Frequency**	**Percent**
>20/year	93	63.7
10-20/year	13	8.9
5-10/year	18	12.3
1-4/year	20	13.7
never	2	1.4
Total	146	100.0

Question 5. What are the most common concerns?

Answers to this question provide additional details to the previous question that regarded the frequency of public inquiries about drinking water safety. 141 out of 146 questionnaire respondents answered this question, many of them with multiple answers. All answers were included in the analysis for this question. 5 respondents did not address the question.

Responses to this question are summarized in table 6. The most common concern was considered to be interpretation of coliform testing results and/or bacteriological safety of drinking water (56.7% of respondents), which is not surprising, since bacteria are most often tested water quality parameter, particularly for small private and communal systems. They were followed by drinking water aesthetics (43.3%), which referred to both public and private systems, and advice on how to improve water safety in private and other small drinking water systems (29.8%).

Other two relatively common topics reported were concerns over the chemical safety of drinking water (an even split between chlorine and chlorination by-products, and other chemicals) for either public or private systems (24.8%), as well as over the quality of the water source for private systems (19.9%). The sixth topic reported was concern over high turbidity and possible parasite presence (9.2%).

Among the rest of the topics, the most serious concerns were over water operator lack of competency and/or inadequate water treatment (5.7%), drinking water being suspected as a source of current illness (4.3%), impact of drilling operations on water quality and quantity (4.3%), and general concerns over public supply water quality and safety, e.g. terrorist attack, watershed protection (5.7%).

The comments section provides additional observations and opinions on the topic. Two respondents specifically noted that the majority of concerns in their area come from owners of private water systems. Other relevant observations were that concerns are also regionally specific, depending on local contamination sources, that the general public seems to think that surface water (i.e. streams in the mountains) are safe to drink without treatment, and that lack of staff was a personal concern of one of the respondents.

Table 6 - The most common public concerns over drinking water safety

Response categories:	Frequency	Percent
coliform testing results interpretation and/or bacteriological safety of drinking water ("Is the water safe to drink?", "can I use it for other purposes?") from public & operators	80	56.7%
aesthetics for public or private water (taste and odour, color, chlorine and chlorination by-products, hardness, staining, iron, hydrogen sulphide)	61	43.3%
how to treat water, e.g. (shock) chlorination of well, dugout, etc.; system maintenance and repair; the cost for putting in a treatment & advice on options	42	29.8%
chemical safety of drinking water, either public or private (chlorine-based chemicals – most often, fluoride, lead, copper, sodium, other heavy metals, nitrates); interpretation of results	35	24.8%
private water source protection; contamination concerns (surface runoff, sewage disposal, manure, pesticides, etc.); source water quality (e.g. well vs. surface):	28	19.9%
high turbidity, possible parasite presence	13	9.2
how to sample and/or test different parameters, cost of testing and concerns about this	12	8.5
lack of operator competency (apathy), inadequate/ deteriorating equipment, inconsistency in water monitoring, slow correction of problems	8	5.7
general concerns over public supply water quality and safety (e.g. terrorist attack, watershed protection):	8	5.7
drinking water suspected as source of illness	6	4.3
water system & safety regulations	6	4.3
concerns over oil, gas and other industrial drilling operations, seismic, etc. (change in water quality, contamination with surface water, to wells going dry)	6	4.3
information on their water system	5	3.6
what to do during a BWA (e.g. how to treat own water):	3	2.1
bottled water quality (i.e. mould in bottles, taste and odour, turbidity)	3	2.1
concerns over cistern water quality	2	1.4
how to clean a cistern	2	1.4
lack of adequate funding for water system improvement	2	1.4
public lodging without proper treatment of surface water (no disinfection or filtration	2	1.4
blue-green algae	1	0.7
drinking water safety for newborn/children:	1	0.7

Question 6. What would you regard as the most important concern for drinking water safety nowadays?

This question was aimed to understand what respondents regard as being the priorities for population protection from drinking water hazards at present time. 133 answers were included in the analysis (130 single choice, 3 unanswered). 13 answers were excluded because the respondents selected more than 1 option (see Table 7).

Table 7 - Response validity for question 6 (single choice required) in the questionnaire

No. of choices selected:	Frequency	Percent
none	3	2.1
1 choice selected	130	89.0
2 choices selected	9	6.2
3 choices selected	3	2.1
4 choices selected	1	.7
Total	146	100.0

6.1. Chemical contaminants

15 respondents (11.3% of all valid responses to this question) considered chemical contaminants to be the most important concern for drinking water safety at present.

Many respondents justified their choice of answer in the comments section. Some regard the lack of knowledge on health effects and treatment difficulties for various chemicals to be of most concern, while others note that chemicals tend to prevail in public concerns, thus public health has to follow the trend. Other respondents note that they consider bacteriological controls for drinking water to be effective enough, thus they see a need to focus on chemical hazards. The list of chemical hazards of concern included: arsenic (3 respondents), hydrogen sulphide, cyanide, benzene, malathion, mercury, nitrates, lead, fluoride, uranium, fertilizers, pesticides, pharmaceuticals, antibiotics, hormones. One respondent remarked that in rural areas arsenic, followed closely by fecal coliforms, are the most important concern, whereas in urban areas it is chlorine residuals.

6.2. Biological pathogens

102 respondents (76.7% of all valid responses) regarded biological pathogens to be the most important concern for drinking water safety nowadays.

The comments section provided a better understanding of their choice. In balancing between biological and chemical contaminants, it seems that several respondents were almost equally concerned by chemical hazards, but they chose this option for: presence of acute (rather than only chronic) health effects, that their specific area is more prone to biological pathogens (because of rural location) rather than this being a general concern, or because of the lack of knowledge and difficult testing for chemicals. On the other hand, other respondents note that biological pathogens would have the largest direct impact on population (outbreak potential), that the public is more concerned with chemicals, but they are personally more concerned with microbes, that parasites are particularly hard to remove, and that discussions with the public would generally focus on what is tested (i.e. bacteria). One respondent specifically mentioned *Escherichia coli* (*E.coli*) O157:H7, whereas other generally referred to agricultural and industrial contamination.

6.3. Taste and odour

No respondent regarded taste and odour issues to be an important concern for drinking water safety nowadays (however, it is important to note that this may be a concern if such issues make consumers choose other, less safe, options).

6.4. Chlorination by-products

Two respondents (1.5%) regarded chlorination by-products as the most important concern for drinking water safety.

One respondent reconfirmed that chlorination by-products raise most concerns in urban areas. The other respondent observed that most enteric illnesses are foodborne and raised the question of THMs formation in the gastrointestinal tract.

6.5. Other water treatment by-products

No respondent considered other water treatment by-products (e.g. ozonation) to be the most important concern for drinking water safety.

6.6. Other

11 respondents (8.3% of all valid responses to this question) regarded other water safety aspects to represent the most important concern for drinking water safety nowadays.

Many respondents here report drinking water safety concerns regarding lack of safety barriers (source protection, lack of multiple barriers, inadequate or insufficient treatment) or lack of operator knowledge. These responses echo common themes referred to in responses to previous questions. Other responses mentioned: public education, public expectation of cheap tap water, public health having less input according to new regulations, and lack of fluoridation.

One respondent remarked here that concerns would vary with region (arsenic, fertilizers and pesticides in rural areas, chlorination by-products in urban zones).

Question 7. Which topics should be part of PHI/EHO training?

This was a multiple choice question, thus percentages are reported for each option independently. The last option was an opportunity for respondents to also propose their own preference – this will be detailed below. Where responses to this option referred precisely and uniquely to one of the previous options, that respective option was included instead of the "other" option. Responses of all 146 respondents were included. All responses to all options were included in the analysis.

7.1. Water treatment basics

133 or 91.1% of respondents recommended water treatment basics as a necessary topic in PHI/EHO training.

7.2. The multiple barrier approach

109 respondents (74.7%) considered the multiple barrier approach to waterborne disease prevention to be a necessary topic in PHI/EHO training.

7.3. Water quality monitoring

123 or 84.2% of respondents would have water quality monitoring as a necessary part of the PHI/EHO training.

7.4. Risk assessment for drinking water systems.

129 or 88.4% respondents would see risk assessment for water systems to be a necessary part of PHI/EHO training.

7.5. Risk management approaches for drinking water

121 respondents (82.9%) would see risk management approaches to drinking water safety to be a necessary part of PHI/EHO training.

7.6. Other topics

32 respondents (21.9%) also made additional recommendations for PHI/EHO training in the field of drinking water.

The most commonly cited topics in this section were: risk communication, water systems inspection, education strategies for public/ operators, hydrogeological assessments, public speaking/ relations and new water treatment technologies (Table 8).

In the comments section, several respondents emphasized that all choice topics in the questionnaire should be part of training. A few other respondents affirmed that all these topics are currently part of environmental health school curriculum; whereas others considered that some topics need more thorough coverage.

Table 8 - Other training topics proposed by questionnaire respondents

Response category:	Frequency	Percent
risk communication, how to debunk myths	6	4.1
inspection of water systems, what to look for, how do devices look like, sampling of source and point of delivery etc.	4	2.7
public education; education of operators and purveyors; education strategies	4	2.7
hydrogeological assessment (GWI), protected wells, etc.	3	2.1
public speaking skills ("salesmanship"); public relations	3	2.1
new treatment technologies, advantages and limitations	3	2.1
water microbiology, waterborne pathogens	3	2.1
water treatment technologies	2	1.4
engineering practices relevant to topic	2	1.4
water contaminant chemistry & migration insoles & aquatic systems	2	1.4
source protection, groundwater threats and safeguards	2	1.4
lab test methods	2	1.4
field test methods	1	0.7
operations and management of water supply systems.	1	0.7
HACCP for water systems.	1	0.7
source to the tap approach is needed.	1	0.7
interpretation of results	1	0.7
emergency response planning	1	0.7
remedial action choices based on test results	1	0.7
cross-connections	1	0.7
risk of hormone-mimicking compounds	1	0.7
All the above. Students should visit small rural systems	1	0.7
as many in-services as possible to update our knowledge.	1	0.7
working with experts.	1	0.7
general common sense – lacking these days.	1	0.7

Risk communication and communication with operators and the public seems to be the most important concern for PHI practitioners, in addition to the questionnaire topics. This often relates to promoting safe drinking water practices to small or private water systems. The comments section also provides more insight into the field inspection and risk assessment needs of PHIs, and shows that quite a few respondents are unsure what is expected of them when inspecting a drinking water system and would recommend more training, either as PHI students or as PHI practitioners. In particular, they would like to get more knowledgeable about water treatment technology.

B. Evidence-based risk management survey (questions 8-13).

The purpose of this section was to assess the ability of PHIs to use evidence to guide risk management decisions in the area of drinking water safety. In designing this section an assumption was made that questionnaire respondents are familiar with common aspects involved in interpretation of water quality laboratory results. The questions were selected to be relevant to application of this basic knowledge to the decision-making process by environmental health professionals, employing concepts of diagnostic testing commonly used in medical science (e.g. screening for a medical condition).

Background

The various limitations of water monitoring as the main quality control measure to assure drinking water quality, particularly for treated water, have been recognized for some time by drinking water experts (Allen et al. 2000; IWA 2004). This is acknowledged in the current "Australian Drinking Water Guidelines" (NHMRC 2004a), which in the overview of the "Framework for Management of Drinking Water Quality" specifies that one of the benefits of the framework is that it "emphasises prevention and places drinking water quality monitoring in the appropriate verification role" (p.2-4). The limitations are also explicit in the New Zealand Ministry of Health Guidelines for preparation and development of public health risk management plans for drinking water systems (NZMOH 2001). After all, the Sydney Water Crisis (Hrudey and Hrudey 2004) was an example of how limited are water monitoring results alone when interpreted as the sole indicator of unsafe water.

In this context, Hrudey and Leiss (2003) addressed the inherent statistical limitations of interpreting monitoring results for rare environmental hazards. The limitations of positive results of a diagnostic test when surveying a target population for a rare disease are known for some time in medical diagnostics. The paper by Hrudey and Leiss 2003 illustrates how such insights are relevant for environmental health, particularly as we move towards detecting more and more potential health hazards at increasingly lower concentrations. In a subsequent paper (Hrudey and Rizak 2004), these insights are presented in relation to screening drinking water quality for hazardous agents such as might be used in terrorist attacks.

In short, Hrudey and Leiss 2003 apply the insights recognized in interpretation of medical diagnostic tests to environmental health testing for contaminants. The concepts of diagnostic sensitivity (DSe), diagnostic specificity (DSp), positive predictive value (PPV) and negative predictive value (NPV) are relevant to this section. The terms are better understood by the use of a 2 x 2 table (Figure 2). The abbreviations used in Figure 2 are defined in Box 3. In this section the term 'hazard' is a generic term used to describe any environmental contaminant (biological, chemical, physical) that is present in numbers, concentration, etc. above what is considered to be a safe level for humans that are exposed to the contaminated medium.

Figure 2 - The relationships between test evidence and reality

(Hrudey and Leiss 2003; Hrudey and Rizak 2004)

		Reality	
		Hazard/Disease Present	Hazard/Disease Absent
Test Evidence	Test Positive	**True Positives** *TP*	**False Positives** *FP*
	Test Negative	**False Negatives** *FN*	**True Negatives** *TN*

$$DSe = \frac{TP}{TP + FN} \qquad DSp = \frac{TN}{FP + TN}$$

In this context, DSe is the conditional probability P[EH|H], i.e. that the evidence will correctly identify a hazard present in the tested sample. Thus:

$$DSe = \frac{TP}{TP + FN} = 1 - \beta$$

DSp is the conditional probability P[EnH|nH], i.e. that the evidence will correctly identify a lack of hazard in the tested sample. Thus

$$DSp = \frac{TN}{TN + FP} = 1 - \alpha$$

On the other hand, in practice we are simply considering the evidence, with no real knowledge about the true presence or absence of a hazard in a sample. In this context, we use PPV as the conditional probability P[H|EH], i.e. that the hazard is truly present given that the evidence indicates the presence of hazard. Thus

$$PPV = \frac{TP}{TP + FP}$$

Similarly, we use NPV as the conditional probability P[nH|EnH], i.e. that the hazard is truly not present given that the evidence indicates no hazard present. Thus

$$NPV = \frac{TN}{TN + FN}$$

Box 3 - Diagnostic testing: abbreviations and definitions

α	the false positive rate
β	the false negative rate
DSe	Diagnostic Sensitivity is the conditional probability of finding a positive analytical result for detection of a hazard, given that it is truly present at a defined hazardous level
DSp	Diagnostic Specificity is the conditional probability of finding a negative analytical result for a hazard, given that it is truly not present at a defined hazardous level
FN	False Negative, a test result indicating the absence of the hazard when it is truly present
FP	False Positive, a test result indicating the presence of the hazard when it is truly absent
NPV	Negative Predictive Value is the conditional probability that the contaminant is not present at a defined hazardous level, given a negative analytical result
PPV	Positive Predictive Value is the conditional probability that the contaminant is truly present at a defined hazardous level, given a positive analytical result
TN	True Negative, a test result indicating the absence of the hazard when it is truly absent
TP	True Positive, a test result indicating the presence of the hazard when it is truly present

Furthermore, Hrudey and Leiss 2003 demonstrate that for low hazard frequencies:

$$PPV \approx \frac{P[H]}{\alpha},$$

which is the case for a 1:10,000 hazard frequency as will be presented below (question 11). The direct implication of this last formula is that the capability of a positive test to correctly predict a true positive sample is inherently low in case of a low hazard frequency in the tested medium. Hrudey and Leiss 2003 note that this effect of low hazard frequency on PPV is recognized in medical diagnostics, but its relevance for environmental monitoring is not commonly recognized among environmental professionals.

Question 8. The source of most errors in public health risk management actions regarding environmental contaminants in drinking water.

Out of 146 respondents, 138 responses were included in the analysis (134 single choice, 4 unanswered). 8 responses were excluded because respondents chose more than one option.

Table 9 - Response validity for question 8 (single choice required) in the questionnaire

No. of choices selected	Frequency	Percent
none	4	2.7
1 choice selected	134	91.8
2 choices selected	7	4.8
3 choices selected	1	.7
Total	146	100.0

Errors in decision-making were on the first place in respondents' opinions, followed by errors in sample collection, errors in data interpretation and, finally, errors in analytical techniques and lab procedures. Only comments that were relevant to the question posed are presented. 102 respondents did not provide a relevant comment or any comment at all.

8.1 Errors in sample collection

Out of all valid responses to this question, 39 respondents (28.3%) estimated errors in sample collection to be the source of most errors in public health risk management actions regarding environmental contaminants in drinking water.

In the comments section they noted that poor sampling technique is often responsible for many false positive results, that additional errors are due to miscommunication, delays in sample delivery and sample contamination during shipping over long distances, and that current sampling requirements provide an incomplete picture.

One respondent noted: "[the] high rate of negative samples following positive ones prove the high likelihood of sampling errors", which seems to suggest that positive samples followed by many negative results upon re-sampling the same medium should be regarded to have been false positives. If this belief is more prevalent, it may indicate a lack of understanding on the inconsistencies of environmental monitoring, particularly for pathogens in treated water. Pathogens are likely to be both heterogeneously distributed in the water volume, and intermittently and infrequently present in treated water (Hrudey and Hrudey 2004, p.427), thus sampling results are naturally inconsistent unless there is heavy contamination.

Another respondent noted that we have to consider the synergistic effects of chemicals in drinking water for public health decision-making. This is a general valid point about environmental risk assessments, but it also seems to suggest that this is the reason why the respondent considers sample collection the most important source of errors.

8.2. Errors in analytical technique and lab procedures

Two respondents (1.4%) estimated errors in analytical technique and lab procedures to be the source of most errors in public health risk management actions regarding environmental contaminants in drinking water. No comments followed their choice of answer.

8.3. Errors in data interpretation

22 respondents (15.9%) estimated errors in data interpretation to be the source of most errors in public health risk management actions regarding environmental contaminants in drinking water.

Some respondents justified their choice by remarking the difficulties to interpret what data actually mean, which results in a lot of guessing and uncertainties on what steps to take when faced with adverse results. One respondent observed that coliform presence as indicator of unsafe drinking water involves a wide range of interpretation from region to region. Other respondents noted that there is a poor understanding and interpretation of total vs. fecal coliform results and of low total coliform counts.

While respondents' comments seem to be restricted to coliform testing for drinking water, they indicate that many respondents do not regard laboratory results of drinking water quality alone to be very informative for public health action. In addition, the comments suggest there are confusions about the significance of total versus fecal coliform presence in drinking water.

8.4. Errors in the decision-making process

71 respondents (51.4%) estimated errors in the decision-making process to be the source of most errors in public health risk management actions regarding environmental contaminants in drinking water.

In justifying their choice of the most important source of errors, several respondents remarked that decision-making may often be influenced more by public risk perception than scientific fact. Lack of standardization and technical training on drinking water quality among public health professionals, poor water operator training and a lack of political will to address issues confronting water systems were also mentioned by a few respondents. Another respondent considered that errors in decision-making result from a lack of information, and from the constant change of protocols based on new information.

One respondent noted that faulty data interpretation in terms of public health significance often results in decision-making errors. Another remarked the need to perform a system-wide assessment before actions are recommended. Other respondents appreciated that the source of errors depend on the type of contaminant (i.e. biological vs. chemical), that chemical results are less reliable than bacteriological results because of being analyzed in private labs, and that untimely results may arrive too late in an outbreak. Yet another respondent expressed doubts in sample data collected by other agencies (e.g. environmental agency), and noted that their decision-making may be influenced by other priorities besides protecting public health.

A few respondents appreciated that the decision-making process includes the previous options. A couple of respondents expressed a belief that most errors lie outside the four options provided, but did not offer any alternative suggestions.

Question 9. What is the lowest accuracy that you would accept from an analytical method, for a specific environmental contaminant, before you would be confident in taking a major risk management action (e.g. issuing a boil water advisory) based on this method indicating the presence of that environmental contaminant?

The next four questions (i.e. number 9 to 12) were formulated to understand how critical PHIs are in assessing evidence and how does this influence their decision-making. The present question sought to understand what would be the minimum positive predictive value that environmental health professionals would expect for a lab result before taking a major risk management action.

Table 10 - Acceptable positive predictive value for an analytical method

Response choices	**Frequency**	**Percent**	**Cumulative Percent**
99%	28	19.2	19.2
95%	55	37.7	56.8
90%	35	24.0	80.8
70%	13	8.9	89.7
50%	11	7.5	97.3
missing	4	2.7	100.0
Total	146	100.0	

A 95% acceptable PPV for an analytical method for environmental health contaminants was favoured by the largest number of respondents (55 or 37.7%). It was followed by 90% (35 respondents or 24%), 99% (28 respondents or 19.2 %), then 70% (13 respondents or 8.9%) and, lastly, by 50% (11 or 7.5% of respondents). 4 respondents (2.7%) did not answer the question. All 146 responses were included in the descriptive statistical analysis.

50 respondents also provided additional comments to this question. The comments section provided further insights into their choices and how they use positive water monitoring results in decision-making.

The most important insight was that many respondents expect a high accuracy for such results because they are aware of the trade-offs of unwarranted regulatory action in terms of public stress and economic burden. Some questionnaire respondents however indicated that they would prefer to treat the result as positive even if they are not completely certain (a couple of respondents added “even if the test is only 50% accurate”). This is consistent with the conservative approach that is expected in the public health profession (“better to be safe than sorry”). While recognizing the conservative value of this approach to population health, one has to remember though that decisions and actions taken in response to a false positive result may also have negative consequences (e.g. reduced public trust, financial loss, political implications).

Several respondents noted that the accuracy level they expect before taking action would vary depending on the nature of contaminant and the risk it poses to population health (i.e. a higher risk would warrant a lower accuracy). Other respondents noted that a major public health action such as a boil order would have to be based on more than just a positive result (e.g. look for corroborative evidence such as system history, barrier efficiency, higher rate of disease, etc.). Obviously, in the environmental health field practices vary across regions and between professionals.

Re-sampling or split samples have been suggested to be the usual course of action in case of positive results by a few respondents. One respondent however remarked that many major decisions are taken proactively before lab data is available, thus analytical precision is not that important.

Judging from their comments, quite a few respondents seem to not have grasped the significance of the question (confused PPV for DSe). They obviously focused on the diagnostic sensitivity of the analytical method (as defined above) and expressed varied expectations on lab accuracy. Some considered issues of cost versus accuracy; others stated that they expect the lab to be fully accurate. Yet other respondent noted the presence of false positive results, as proven by subsequent negative results on re-sampling.

*Question 10. What is the **lowest** accuracy that you would accept from an analytical method, for a specific environmental contaminant, before you would be confident in **not** taking a major risk management action (e.g. **not** issuing a boil water advisory) based on this method indicating the **absence** of that environmental contaminant?*

This question sought to define what would be the minimum negative predictive value that environmental health professionals would expect for a lab result before ruling out the need for a major risk management action.

Table 11 - Acceptable negative predictive value for an analytical method

Response choices	Frequency	Percent	Cumulative Percent
99%	47	32.2	32.2
95%	43	29.5	61.6
90%	29	19.9	81.5
70%	8	5.5	87.0
50%	8	5.5	92.5
missing	11	7.5	100.0
Total	146	100.0	

Respondents generally expected a high accuracy before not taking action (Table 11). A 99% acceptable NPV for an analytical method was favoured by the largest fraction of respondents (47 or 32.2%). It was followed by 95% (43 respondents or 29.5%), 90% (29 respondents or 19.9 %), then 70% and 50% (each with 8 respondents or 5.5%).
11 respondents (7.5%) did not answer the question. All 146 responses were included in the analysis.

41 respondents also provided additional comments to this question. The comments section provided further insights into their choices and how they use positive water monitoring results in decision-making.

Many respondents duplicated their comments for this question from the previous one (e.g. "see above"). Since some of these comments were not very applicable to the present question, this may indicate misunderstanding, lack of attention, or both in the case of the particular respondent. For example, some respondents noted again that public health action is rarely taken based on just one lab result, although this is not relevant for the NPV question. Along the same line, quite a few respondents seem to not have grasped the significance of the question (confused NPV for DSp, and discussed laboratory issues similar to those for previous question), but also not realized that we refer to not taking action. Several respondents did not answer because they considered the question confusing.

New observations specific to this question were that we need to have a proactive approach, we need to look for other, corroborating evidence before not taking action (e.g. raw water results, sampling conditions, historical test accuracy), and that lab results may not be the only consideration and might still take action even if results are negative.

Question 11. The positive predictive value for a rare environmental hazard

This question was provided mainly as an example to test the respondents' use of lab results and how they guide their decision. While providing a mathematically correct response is desirable, the most important aspect however was to test what their instinct would be in face of a positive lab result for a rare water contaminant.

The question required to estimate the accuracy of a hypothetical *Giardia* test, while provided with defined diagnostic characteristics (which are excellent compared to most analytical methods used in environmental health) and an estimated hazard frequency in the respective medium. Based on the definitions presented in the introduction to this section, for a diagnostic test with 99.9% sensitivity and 98% specificity, if the prevalence of pathogen in treated drinking water is 1/10,000 (see Figure 3), then the positive predictive value of the test is 0.497%, or about 0.5%. Therefore, the correct option among the choices provided was 0-5%.

$$PPV = \frac{TP}{TP+FP} \Leftrightarrow PPV = \frac{0.999}{0.999+199.98} \cong 0.00497$$

Figure 3 - Calculation of result for Giardia test question

		Giardia		
		present	absent	
Evidence	positive	0.999	199.98	200.979
	negative	0.001	9799.02	9799.021
		1	9,999	10,000

For this second question, out of all 146 respondents in the questionnaire survey, only 5 (3.4%) of them picked the correct option (0-5%). The vast majority of respondents (105 or 71.9%) chose the highest certainty option (i.e. 95-100%), obviously ignoring the information on pathogen prevalence in the tested medium. For the rest, 17 respondents (11.6%) chose the 80-95% option, three (2.1%) the 50-80% option, one (0.7%) the 20-50% option, four (2.7%) the 5-20% option, and eight (5.5%) the "no idea" option. Three respondents (2.1%) did not answer this question. All responses to this question were included in the statistical analysis (see Table 12).

Respondents were also provided with the opportunity to comment on this question or provide reasons for their choice of answer. The qualitative analysis of these comments provides further insight into how environmental health professionals interpret laboratory evidence for decision-making. Only 45 out of 146 respondents explained their choice in the comments section provided to them.

Table 12 - Positive predictive value choice for rare hazard question

Response categories:	Frequency	Percent
Almost certain (95-100%)	105	71.9
Very likely (80-95%)	17	11.6
More likely than not (50-80%)	3	2.1
Less likely than not (20-50%)	1	.7
Very unlikely (5-20%)	4	2.7
Extremely unlikely (0-5%)	5	3.4
No idea	8	5.5
missing	3	2.1
Total	146	100.0

The respondents choosing the highest option (95-100%) provided the bulk of comments. While some explanations were too short or incomplete, it would seem that almost half of these respondents considered diagnostic sensitivity to be the same as the positive predictive value for a test. A few other respondents in this category were generally comforted by the test credentials, and focused more on issues of viability, infectivity or susceptibility to disinfection of *Giardia* cysts detected, or how representative the sample is for water quality in the system, which were not the object of this question. Yet other respondents indicated that they would believe the result to be true, but would still try to corroborate with other data, and wait for re-sample result, i.e. would not take major action based on single positive result (a sensible approach as long as meaningful follow-up is pursued quickly).

Moreover, one respondent in the "almost certain" category explicitly refused to second guess the validity of the lab result, and insisted on treating any positive result as true until further results arrive. Also, several respondents excused themselves for either not having any statistical training or not having refreshed it for a long time. To note, one respondent remarked that in their city they detect *Giardia* every time they conduct tests.

It thus became apparent that most respondents choosing the high confidence options (95-100% or 80-95%), while correctly understanding the distinction between positive test results and true positives, did not realize that *Giardia* test characteristics presented (i.e. DSe= 99.9% and DSp=98%) can only be defined in a context where we know with certainty whether we are having a true positive or a true negative *Giardia* sample. This is precisely the opposite of what happens when testing for contaminants in the environment. That is, the respective professional only knows for sure that the lab result is positive, but cannot have any idea whether this result is correct or not. In other words, they confused diagnostic sensitivity with the positive predictive value for this test.

In addition, it became evident that none of the above respondents appreciated even intuitively the impact that the low *Giardia* prevalence in the respective media would have on the positive predictive value of the *Giardia* test. 83.5% of respondents (Table 12) believed this result was "very likely" or "almost certain" (i.e. confidence greater than 80% that the result is true). In effect, the high levels of diagnostic sensitivity and diagnostic specificity for this test were enough to assure their high confidence in the validity of the positive result. Such misunderstanding is not new. Hoffrage et al. (2000) reported similar results for hypothetical medical diagnostic questions given to faculty, staff and students at the Harvard Medical School.

The comments of most respondents choosing the low certainty of result (under 50%), including those who correctly responded to question 11 (i.e. 0-5%), indicate they have realised the impact that a 98% diagnostic specificity in the context of a 1:10,000 prevalence of hazard would have on PPV, resulting in false positive being more likely than true positive *Giardia* results.

The respondents choosing the "No idea" option are likely to not question any laboratory result on environmental contaminants in their practice.

The answers to the above question are directly relevant to the interpretation of treated water quality monitoring results by public health professionals.

The purpose of water treatment and other preventive measures is to remove environmental health hazards from water. Thus, for any responsible water supplier the presence of such contaminants in drinking water is a rare occurrence. Moreover, no analytical method for water contaminants has 100% diagnostic specificity, i.e. even the best labs cannot completely avoid false positive results. Therefore, when monitoring for rare contaminants in treated water, false positives are inevitable, i.e. true positives will be exceeded by false positives, lowering the positive predictive value to levels that make risk management decisions uncertain.

This is not something that can be sensibly improved by better sampling or analytical techniques. It is an inherent limitation, the result of intensely pursuing environmental contaminants at very low concentrations. In a way, this reminds of the Heisenberg Uncertainty Principle in atomic physics, i.e. the intense pursuit of evidence at low levels of matter may introduce, by itself, large uncertainties in the result.

Unfortunately, most questionnaire respondents failed to recognize this limitation of finished water monitoring. In this question, the accuracy for *Giardia* test was about 0.5%. This is in contrast with the common level of accuracy expected by

80.9% of these professionals (Table 10) from an environmental contaminant test before taking action based on results of this test, i.e. more than 90% accuracy.

While questionnaire respondents were asked to answer these questions with their "first instinct", this "first instinct" is very likely the only factor in the decision-making in their busy environment where they have to decide quickly if action is needed. Regardless of the rarity of the hazard, it results thus that most respondents would still place a very high level of trust in the positive result of the laboratory analysis.

Question 12. For the circumstances of question 11, if you have any remaining concerns about this evidence, how would you improve certainty for this result?

This question was open-ended, thus I only provide a qualitative analysis of results. This question further explored the respondents' understanding of lab evidence, looking at how they would improve it for good decision-making.

A variety of suggestions were provided. They are presented in Table 13 in the order of their frequency of occurrence, starting with the most common. The options are not mutually exclusive (i.e. one respondent may have proposed more than one option, thus its response may be present in more than one place). 57 respondents to previous question (39%) either did not respond this question or did not provide a suggestion relevant to the topic. All 146 responses were included in the analysis for this question.

The most common instinct of the respondents was to improve certainty of the result by re-sampling the medium (i.e. treated water) and analysing it using the same analytical method (35.6% of all respondents to the previous question). A second common instinct was to look for additional corroborative evidence: sample other locations, corroborate with other analyses or data, investigate water supply, sample and analyse raw water, look for indications of a gastrointestinal outbreak, etc. A third action would have been to review sampling and/or analytical technique used. A fourth one would be to re-sample and use another analytical test and/or another lab.

Comparatively few respondents indicated that they would have attempted to improve test result certainty by further analysing the same sample using the same or a different analytical method (i.e. split samples, sequential analyses), which eliminates the large uncertainty due to re-sampling. To improve certainty of medical diagnostics of rare diseases, we would test the same or another specimen from the same person for the respective disease. However, variability of specimens in a human patient is expected to be far more limited than variability between repeated water samples when contamination may be intermittent, thus the medical approach is more similar to using split water samples.

Table 13 - Suggestions to improve the certainty of Giardia result

Suggested solutions	No. of respondents	Percent of respondents
Re-sample and/or re-analyse		
re-sample and analyse	52	35.6%
re-sample and find/use another analytical method	6	4.1%
re-sample and use another lab	5	3.4%
split samples	4	2.7%
sequential analyses	4	2.7%
Other related: re-analyse same sample, use quality control methods (spikes, blanks, etc.)	3 or less	2.1% or less
Review/modify monitoring program		
sample at other locations in the water system	14	9.6%
increase sampling frequency	11	7.5%
review analytical procedure	10	6.9%
review sampling procedure	8	5.5%
increase sample size	4	2.7%
Gather additional evidence		
corroborate with other analyses (e.g. turbidity, *Cryptosporidium*) and/or data (environmental, history, etc.)	13	8.9%
further investigate water source and water treatment	8	5.5%
sample and analyse raw water	5	3.4%
look for increase in gastro-intestinal disease incidence in the community	5	3.4%
look for *Giardia* cysts viability / infectivity	4	2.7%
Other responses		
consult a specialist	5	3.4%
the test as presented was conclusive (implies no further action is required)	5	3.4%

A small minority of respondents (5 or 3.4%) specifically indicated that in their opinion the *Giardia* result presented was conclusively positive, thus no further action to confirm the result is necessary. This response represents a serious misinterpretation of the capabilities of the hypothetical (but realistic) monitoring method presented and is likely to lead to misguided risk management actions.

Question 13. Does the Precautionary Principle influence your risk management decision-making?

The question aimed to verify participant understanding of an important environmental risk management principle that is often invoked in circumstances of conflict where tradeoffs have to be carefully balanced.

The principle that became known as the Precautionary Principle has been first formulated by the United Nations Conference on Environment and Development in 1992 in the Rio Declaration on Environment and Development. Principle #15 in the document proclaims: "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation." (UN 1992). There is no unique version of this principle. The principle has since then been extended in practice to cover circumstances where scientific evidence is insufficient, inconclusive or uncertain and there are indications through preliminary objective scientific evaluation that there are reasonable grounds for concern for potentially dangerous effects on the environment, human, animal or plant health (EC 2000).

The purpose of the principle is to acknowledge that uncertainty is inherent in managing risks. This means that public health and environmental protection agencies still have to take steps to reduce potential harm, even when uncertainties remain. The precautionary principle accepts a lower level of proof of harm be used in policy-making if the consequences of waiting for more supporting evidence might be very serious and/or irreversible. Versions of this principle are included in environmental laws in some European countries and the principle is often referred to in UN documents.

In the respondents' own opinion, 80 (54.8%) considered that the Precautionary Principle does influence their own risk management decision-making, 13 (8.9%) considered that it does not, 41 (28.1%) were not sure, and 12 (8.2%) did not answer the question (Table 14). However, many respondents that affirmed the Precautionary Principle influences their decision-making did not provide a clear definition of this principle.

Table 14 - Does Precautionary Principle influence individual risk management decision-making of respondents

Response categories:	**Frequency**	**Percent**
No	13	8.9
Yes	80	54.8
Not sure	41	28.1
missing	12	8.2
Total	146	100.0

Please also state what you believe the Precautionary Principle means:

To this question, 8 respondents (5.5%) gave a full and complete definition in various forms; 51 (34.9%) gave a certain and clear, but incomplete definition (protection-focused); 15 (10.3%) were uncertain but tentatively provided the same incomplete definition; 14 (9.6%) provided an unclear definition, more related to being cautious all the time; 5 (3.4%) provided a completely wrong definition; 8 (5.5%) affirmed their lack of knowledge in various forms; 34 (23.3%) did not answer the question at all.

Table 15 - Definition of the Precautionary Principle provided by respondents

Definition accuracy	**Frequency**	**Percent**
right, complete	8	5.5
right, incomplete	51	34.9
right, incomplete, uncertain	15	10.3
unclear	14	9.6
wrong	5	3.4
don't know	19	13.0
missing	34	23.3
Total	146	100.0

Definitions of terms used to describe response accuracy:

Wrong:

- Wrong definition or response indicating a lack of understanding: e.g. 'any water quality issue that is a safety concern' / 'perceived risk vs. actual risk' / 'the decision-making process to prevent/reduce an adverse outcome' / 'a plan (principle) in place to prevent harm to humans and environment'.

Right, incomplete:

- Protection-focused responses: Err on the side of caution (safety) / Better to be safe than sorry (when public health is at stake) = appreciates uncertainty, acknowledges tradeoffs, but errs on the side of public interest in order to prevent adverse consequences. Some spelling mistakes, but the understanding is clear.

Right, incomplete, uncertain:

– Same as 1, but unsure of the response provided.

Unclear:

– Responses that indicate no clear appreciation for tradeoffs, advocating protection at any costs: 'Be more cautious' / 'Have a margin of safety' / 'If impact unknown or uncertain, prevent it' / 'Require evidence of harmlessness', etc.

Don't know:

– Responses that indicate no knowledge about this principle: 'I have no idea' / 'Don't know'/ 'Never heard' / 'Not sure what you mean' / 'What is the Precautionary Principle?'

Right, complete:

- The response provides the full Precautionary Principle definition elements: appreciates uncertainty and understands trade-offs, but errs on the side of caution due to concern for unacceptable consequences to humans and/or irreversible damage to the environment.

In the comments section a couple of respondents noted that the principle is a hard and difficult concept with respect to risk management and that there are always conflicting scientific studies. Another respondent remarked that their decision-making is context sensitive.

80 of the 93 respondents (86%) that attempted to provide a definition for the Precautionary Principle expressed in various forms the protective principle of public health, which is to err on the side of caution in decision-making when there are indications that health of the public can be affected even if there is no definite evidence to support this assumption. This attitude is conservative and we normally expect it from a public health practitioner given their mandate to place the public's health above all other concerns.

While this principle has many similarities with the Precautionary Principle, it is however different from the principle itself as stated above. The Precautionary Principle itself has often been subject of debate and of various interpretations based on different ethical values and principles (Martuzzi and Bertollini 2005). Public health professionals interpreting this principle within the utilitarian public health ethical framework should exercise caution to avoid a narrow understanding of this principle as well as a futile search for zero risk.

The Precautionary Principle does not promote protection at any costs. WHO defines health not just as the absence of disease, but also well-being and good quality of life (WHO 1948). Economical and social penalties of public health actions will have to be balanced with the estimated benefit, seeking for the best alternative to maximise "common good". For example, the European Commission, an important promoter of the principle, recommends that the implementation of the principle should be based on an objective risk assessment process (EC 2000). Such process should carefully consider risk tradeoffs and their impact on population health as per WHO definition of health. However, the Principle does shift the "burden of proof" from proving harm to proving lack of harm in situations that are potentially dangerous to population health. In the area of drinking water, the application of this principle would thus require a responsibility on the part of the water industry to prove that they are protecting public heath.

While the majority of respondents did not express a clear understanding of tradeoffs in environmental health risk management decision-making where the Precautionary Principle is involved, it is quite likely that they do deal and accept some tradeoffs in their professional activity. It is likely then that a more thorough understanding of the risk management approach and principles would improve their decision-making, since it would give them an instrument to judge and balance tradeoffs, and provide better scientific basis for their decisions.

Question 14. Comments on any related issues

At the end of the questionnaire we provided a further opportunity for participants to comment on the questionnaire and related issues. 35 respondents took the time to share opinions here. Their comments provided further insights into the issues, concerns and recommendations they have for drinking water safety in Canada.

Some themes have already been mentioned in the comments to certain questions, such as concerns over their reactive role in drinking water; the uncertain safety in the case of drinking water provided by small rural systems, both residential and non-residential (four respondents); the passive role that many PHIs have versus municipal water supplies, e.g. only respond to public complaints on aesthetics(three respondents); the importance of continuing and specific drinking water safety training for PHIs (three respondents); and the frustration towards governmental and water operator complacency that compromises the safety of drinking water (two respondents).

Related to the above themes, three respondents advocated for a stronger role of public health professionals in drinking water issues; yet another one considered that the drinking water field is too technical and their role should only be initial referral and backup for water monitoring results. Other respondents noted the positive impacts of new safe water legislation (British Columbia); the advantage of protocols for positive bacteriological results developed after Walkerton and North Battleford outbreaks to facilitate PHI decision-making; that PHIs must take responsibility to follow all water results for all water systems; or that PHI staff is so stretched and thin that training may not help improving drinking water safety, and that more resources and more PHIs are desperately needed.

Several respondents commented on more specific drinking water safety issues: that drinking water safety issues affect primarily vulnerable populations (first nations and rural areas); that water should be regarded as contaminated unless proven otherwise; that drilling licences should stress the use of non-contaminated water for drilling (to prevent aquifer contamination); that would be useful to have an inventory of all drinking water systems; that particularly in rural areas blue-green algae are becoming a serious issue that has to be dealt with; or wondered about how to interpret total coliform results regarding consumer risk and what better water quality indicators exist.

Several respondents commented on the questionnaire design and content: eight respondents appreciated our initiative to address drinking water safety training needs and/or expressed their interest to see the result of the study; one respondent remarked that the questionnaire took longer than 10-15 minutes; another respondent considered that the questions are confusing and complicated, which proves the questionnaire authors do not live in the 'real world'.

3.3. Public health and drinking water safety

The key characteristics of current public health practice to assure drinking water safety are summarized in this section. This summary is based on literature review and the findings of the study (interviews and questionnaires).

Drinking water safety programs

The health care and public health activity in every province is organized in several regional health authorities (RHAs). RHAs are responsible to assure health care and disease prevention for citizens in their region. The public health activity responsible for disease prevention in every RHA is organized at the level of a regional public health unit, managed by a medical officer.

Due to its general mandate, public health has to cover large and diverse areas of responsibility. A typical public health agency organizes disease prevention in several programs, one of which is environmental health. The responsibility for drinking water safety is discharged at the level of the environmental health program, usually altogether with other areas, such as food safety, recreational water safety, safe housing, indoor air quality, etc. In most Canadian provinces and Australian states, trained and certified environmental health officers (EHOs) / public health inspectors (PHIs) are responsible for enforcement of environmental health regulations, including drinking water safety.

In Canada, large public health agencies (usually in a RHA centered on a large city) would have large and diverse environmental health responsibilities, and thus hire more enforcement officers. In these units, it is quite common then to have staff formally specialized in a certain area. Depending on the size and needs, they would either have water safety specialists (regular staff with more water safety training, i.e. resource person for their team) or even dedicated water safety consultants. Smaller public health agencies are often limited in resources and staff and would not allow such specialization. In this case, every PHI would be responsible for water safety activity in their district. Sometimes, senior PHIs would be an informal resource person for their team.

Drinking water systems in Canada

Licensing and inspection of drinking water systems over a certain size (i.e. 'regulated' systems) and training and certification of their operators is usually the responsibility of the environmental body (e.g. Ministry of Environment) or equivalent. Local environmental offices approve water treatment plant designs, issue licenses, renew licenses, and inspect facilities. They would consult the public health agency (i.e. district PHI or water consultant PHI) in case of adverse results that suggest public health risks (e.g. high turbidity, positive bacteriological results in finished water), discussing the need for public advisories (e.g. boil water advisory).

Two notable exceptions to this general rule are British Columbia and Quebec. In B.C., as noted before, public health is entirely responsible for drinking water in the province including water system licensing and training of operators, and thus receives enough funding to hire dedicated drinking water staff. In Quebec, the drinking water safety enforcement activity also lies with the environmental body. Public health agencies in this province do not employ enforcement officers, but provide environmental health consultancy to environmental enforcement.

Small non-regulated public drinking water supplies include: communal supplies (water co-operatives, trailer parks, potable water haulers) and public non-residential systems (institutions, food establishments, recreation areas, hotels/motels, churches, community halls, and other similar systems). These public drinking water systems are not formally the responsibility of any agency in most provinces. Thus the responsibility to assure they provide safe drinking water typically falls by default entirely onto the public health agencies, given their general mandate to protect population health. New regulations in progress to be adopted in Ontario might formally assign the responsibility for some of the above to the public health agencies.

The majority of Canadians benefit from high-quality drinking water provided by drinking water systems that are safe and robust. Large municipal systems generally have good funding and with a low cost of water per capita can afford to consistently provide safe drinking water and have all controls in place. However, as systems get smaller, there are generally more difficulties to assure safe drinking water, particularly in times of challenge (e.g. drought, spring or storm runoff). Small municipal and non-municipal water systems are the most challenged since they often have less treatment barriers and outdated technology, less trained or (for non-regulated systems) untrained operators, no continuous supervision, and a high cost per capita resulting in limited resources for operation, maintenance and upgrades. In addition, many unregulated small water systems and private wells often undergo irregular water testing or no testing at all.

Safe drinking water surveillance

The common approach adopted by public health to protect population from drinking water health risks is to review water quality monitoring results and issue a boil water advisory when monitoring results indicate microbial contamination in drinking water in order to prevent consequences to consumers. In rare cases of chemical or toxin contamination (e.g. algotoxins), a 'do not drink water' advisory may be issued. Safe drinking water surveillance is commonly based on bacteriological testing, which consists of sampling and laboratory analysis of raw and treated water samples for presence of total coliforms, fecal coliforms, and, more recently *E.coli* bacteria. Pathogenic protozoa or viruses are not commonly monitored, in part because of reliance on bacterial monitoring to indicate fecal contamination, and in part because such analyses are challenging and expensive (the only exception at present is that some large municipal systems sample and test regularly for *Giardia*). Chemical monitoring of drinking water is done on a large variety of potential contaminants for compliance with numerical water quality guidelines. Regular sampling is done by water operators, with environmental and/or public health inspectors collecting grab samples during inspections.

The schedule of testing for these indicators varies with every province, the size of the system and quality of water source. The recommended schedule of sample collection for bacteriological testing is usually daily for large municipal systems, weekly for smaller systems (municipal or non-municipal), and monthly or less for non-regulated systems using groundwater that is not under direct influence of surface water. Testing for DBPs is recommended to be done four times per year by municipal systems. Chemical safety testing is performed regularly by municipal systems, but less often (annually or even less) by unregulated systems. Private system testing is optional, while public health agencies may encourage it particularly in high risk areas. In practice, compliance to the monitoring schedule might vary due to various reasons, and part of the PHI activity is to assure operator compliance to this schedule. This is more often the case with small water systems that lack a full-time operator.

While not a formal requirement in most provinces, some larger public health agencies have also moved towards organizing surveillance data in water systems inventories, and some are currently in the process to perform formal water supply risk assessments for non-regulated systems, based on a local risk grading system. As noted in the literature review, in British Columbia and Ontario risk assessments of some form became recently a legal requirement. Outside these two provinces, smaller public health agencies generally lack resources and staff to initiate a similar program. By comparison, in the Australian state of New South Wales the Water Safety Unit in the state Department of Health maintains a water system inventory for all water supplies in the state, and provides consultancy and training on water safety to local public health agencies.

There is no surveillance system of drinking water safety incidents in place in any Canadian province that documents and centralizes information on system failures and near failures to support efficient operational and enforcement learning from past incidents, and inform provincial and regional planning of improvements to respond to future challenges.

Training and certification of water operators

Formal training and certification of water operators for regulated drinking water systems is done entirely by the environmental agency, typically with no intervention from public health agencies. British Columbia is, of course, an exception to this rule due to the legal public health responsibility to assure safe drinking water, which includes operator training.

There is no formal training requirement for water operators for non-regulated water supplies, and typically these operators lack drinking water safety training and a clear understanding of the risks in their system. District PHIs (by default responsible for the safety of drinking water provided by these supplies) would typically provide telephone assistance with testing and interpretation, and, within the constraints of their (usually) limited time availability, would instruct on drinking water safety procedures and system maintenance during field inspections. As mentioned above, the inspectors have many responsibilities in addition to drinking water safety in their district.

Generally, no formal support (consultancy and information resources) is organized for small water system operators. Some local initiatives have resulted in the production of educational materials in the form of brochures on safe drinking water practices for private systems owners.

Emergency after hours and weekend response

Following the waterborne outbreaks in Walkerton and North Battleford, some form of emergency after hours and weekend response to adverse monitoring results, disease surveillance and/or public complaints has been organized in all public health agencies I visited. In most provinces a direct or operator served telephone line would connect to either the medical officer on-call or, in some regions, to the EHO/PHI on call. Pager systems or secondary telephone lines are used in other provinces. The officer on duty would then take charge if there are possible public health implications and investigate or contact the responsible inspector to investigate if the situation warrants it.

Prevention and public education

Most public health professionals are aware of the importance of public education on safe drinking water practices as an important and effective preventive approach to protect population health. However, limited funding and staff often restricts prevention activities. Drinking water safety is an area that tends to get less attention due to the general success of the water industry in preventing waterborne disease in Canada. Resource availability is a major factor in organizing safe water public education programs. As a result, the extent of such activities varies largely between provinces and among regions.

Water safety risk communication to small system operators and general public is an important determinant to the success of other safe water intervention strategies. In promoting safe drinking water practices, public health professionals are confronted with different public perceptions on drinking water health risks as well as a misconception that drinking water should be cheap. In some areas, source water is often presumed safe based on its pristine mountain location, groundwater source, or simply based on a belief that water was always safe. Sometimes, such belief persists in spite of recurring adverse water source monitoring results, for example for fecal coliforms. This reduces the efficiency of activities promoting preventive measures for water supplies, including the need for multiple barriers. In addition, according to some participants, PHIs would often advise treatment upgrades for high risk systems, but financial limitations become apparent all the time and limit the effectiveness of their advice. In some places, water regionalization is being promoted as an alternative to reduce production cost per capita and improve access to better water sources.

Many interviewees and questionnaire respondents maintain an understanding of the correct priority for drinking water safety that primarily is to prevent microbial contaminants from reaching consumers. However, some study participants seemed to underestimate the reality that biological contaminants still present the greatest and clearest risk to drinking water safety. In this context, chemical hazards were regarded sometimes to be a more important water safety concern. In some cases, their judgement was likely based on a belief that pathogens are well taken care of at present. They also seemed to forget or not understand that health risks for most chemicals present in the drinking water guidelines are often an unproven hypothesis, whereas risks posed by biological pathogens have been proven over and over again. Maintaining a correct perspective on the most important health risks in drinking water is essential to effective prevention and education programs.

Other challenges

In addition to drinking water systems surveillance, public health professionals, particularly medical officers, are sometimes required to provide expert advice on health risks from specific environmental hazards in incidents that are suspected to affect source water quality (e.g. lead, boron, algae, hydrocarbons, sour gas), or for future industrial or agricultural developments. This includes requests for official public health opinions in litigation that involves environmental contamination. There are many challenges to provide an objective assessment of the potential public health consequences in a specific contamination situation.

Co-operation with other stakeholders

Public health co-operates with municipalities and other agencies, particularly the Ministry of Environment, to promote drinking water safety. Within the limitations of their time, district PHIs often maintain direct relationships with municipal water operators, particularly in cities. The level of co-operation with regulatory agencies may vary, but sometimes environmental officers provide consultancy and support on more technical aspects of water treatment, and may involve PHIs in joint inspections of municipal systems when there are public health issues. However, according to some participants, they sometimes feel that their environmental colleagues are guided by somewhat different priorities and have not always held population health to the same priority for prevention as they do. Whether this was due to miscommunication on one side or both, or is a result of different approaches will have to be clarified by future research. In some areas, different approaches and interests in water resource management and/or drinking water are being addressed in consultative committees with participation of all relevant stakeholders.

Approaches to drinking water safety

Various approaches are employed across Canada and Australia to assure drinking water safety. Some Canadian provinces (e.g. British Columbia, Ontario) or Australian states (e.g. Victoria) have moved towards a regulatory approach, adopting specific safe water legislation that enforces improvements in drinking water safety management. Alberta has not adopted separate safe drinking water legislation, but approvals are issued under the potable water authority of the Environmental Protection and Enhancement Act. In Alberta, the regulatory approach promotes best practices in the water industry by specifying requirements in approvals including a regulatory requirement to meet the health-based limits of the Guidelines for Canadian Drinking Water Quality. For enforcement, public health professionals use the more general provisions of the Public Health Act and regulations.

Some participants reported particular challenges in enforcement and preventive actions (e.g. education) in regions of jurisdictional overlap or in "grey" areas (i.e. areas not clearly covered by legislation that governs any governmental agencies). Examples of jurisdictional overlap may be communities with mixed aboriginal/non-aboriginal population with a common water supply; examples of grey "areas" are water supplies for Métis communities or water systems whose regulated status is interpretable (e.g. depends how connections are counted). In general, public health agencies tend to take the extra step and assure minimal coverage even when jurisdiction in unclear, because of their general mandate to protect population health. However, not having clear jurisdiction and not getting credit for the extra effort limits available resources and preventive activities.

In regards to public health actions to prevent waterborne illness, practices in calling advisories vary between provinces and across regions, depending on local action protocols and experience. Solutions also vary, with some regions having boil advisories for months, even years.

Training and assistance

Participants have identified many training needs and priorities, some related to more immediate needs (e.g. water biology and emerging pathogens, interpretation of water monitoring results), other more long-term (risk-based approaches to drinking water safety, multiple barrier approach). This section will be expanded in the recommendations (section 4.3.2.).

4. RECOMMENDATIONS

The basic causes of waterborne disease will always be present, in particular human and animal fecal contamination. In the last 150 years we have become increasingly adept at controlling population exposure to pathogens via the drinking water route. We are now faced with a new frontier: we have to assure that we provide this control consistently, and for every Canadian. This is addressed internationally by moving beyond audit-based management and towards preventive, risk-based, drinking water management (NZMOH 2002; IWA 2004; NHMRC 2004a; WHO 2004a). While ad-hoc approaches to risk management have been used in the water industry in the past, it is time to move from implicit to explicit risk management, and make this the formal approach to drinking water management for drinking water systems of any size (Pollard et al. 2004).

Adoption of a formal risk management approach to assure drinking water safety cannot be done overnight. This process requires political and executive management support, and a clear commitment of resources. For example, time for staff training will have to be allocated by public health agencies. However, risk management training for drinking water will pay later many times more by enabling public health professionals to be truly proactive in the benefit of public health. Table 16 introduces several key principles that will have to be observed in order to implement a preventive, population health approach to drinking water safety for the benefit of all Canadians.

Table 16 – Summary of key principles for safe drinking water

4.1.1. Population health and drinking water safety
4.1.1.1. Drinking water is vital for survival. Assuring sustainable water resources should be a governmental priority.
4.1.1.2. Water is an important health determinant. Unsafe water is an important contributor to the global burden of disease.
4.1.1.3. Drinking water should be safe and aesthetically acceptable to consumers.
4.1.1.4. As the only agency that has population health as its primary concern, public health agencies should be major players in the field of drinking water safety.
4.1.1.5. Drinking water safety strategies should be developed based on population health objectives.
4.1.1.6. The clearest health risks to consumers of drinking water are posed by microbial contaminants.
4.1.1.7. Small water systems (community and private) present the greatest concerns for drinking water safety.
4.1.1.8. Water system operators are public health professionals.

4.1.2. Principles for management of drinking water safety

4.1.2.1. Source water should never be presumed safe because it may always be subject to fecal contamination.

4.1.2.2. Management of drinking water safety should be a proactive rather than a reactive process.

4.1.2.3. Management of drinking water quality should follow a total quality management approach based on risk management principles.

4.1.2.4. Drinking water systems should be designed in response to a system-specific, source to tap, risk assessment process.

4.1.2.5. Management of drinking water safety should recognize that human error is unavoidable, and thus account for it in the planning of preventive measures.

4.1.2.6. Continual improvement is essential to maintain consumer confidence and to be able to respond to future challenges to drinking water safety.

4.1.2.7. Safe drinking water can best be achieved by close co-operation and partnership with all stakeholders, including consumers, in a transparent fashion.

4.1.3. Risk assessment

4.1.3.1. Water system priorities should be based on the estimated magnitude of system-specific health risks rather than on the mere presence of hazards in the environment.

4.1.3.2. Risks should be assessed at all points throughout the water system, from source to tap.

4.1.3.3. Furthermore, system-specific risks should be addressed in the order of their magnitude, starting with the very high risks.

4.1.4. Risk management

4.1.4.1. Measures to prevent contamination from entering the system are more effective and cheaper than complex water treatment and/or extensive water quality monitoring.

4.1.2.2. End-of-pipe verification of drinking water quality should only be used as a final confirmation that drinking water system performance and management is adequate.

4.1.4.3. Targeted, system-specific, monitoring for the most likely contaminants is preferable to non-targeted monitoring for a large set of contaminants.

4.1.4.4. No single drinking water safety barrier is 100% effective against contamination. A drinking water system should have and maintain multiple effective barriers.

4.1.4.5. Social, cultural and economic trade-offs of various risk management options should further be considered in decision-making, seeking the greatest good.

4.1.4.6. Good communication and risk communication skills are important to achieve consumer confidence, support and compliance.

4.1.5. Regulatory and surveillance aspects
4.1.5.1. Development of non-regulatory risk management options should be considered, while preserving regulations that allow enforcing public health protection.
4.1.5.2. Formal support for operators (consultancy and information resources) should be organized and funded at provincial or regional level.
4.1.5.3. Long-term solutions to assure safe drinking water require investigation of various water management solutions.

4.1. Key principles

4.1.1. Population health and drinking water safety

4.1.1.1. Drinking water is vital for survival. Assuring sustainable water resources should be a governmental priority.

Water is essential for human and ecosystem survival. We need water for many activities (Gleick 2003; Moeller 2005) (agriculture, food preparation, resource extraction, industrial processes, etc.) but the most important is for drinking. We cannot live without water but for a few days. Except for air, there is nothing more necessary for basic survival. If there were no other water sources, we would even have to drink contaminated water. However, severely contaminated water can cause serious sickness and death.

Availability of clean drinking water thus predates any other uses for water that we have. While we may need water for many other uses, none of these can be given preference to assuring people will always have clean, safe water available to drink and for personal hygiene. Preserving enough water sources for drinking water production, with the foresight of future population growth, is thus paramount. In this respect, as will be presented later in this section, protection at the source provides critical assurance that the water we drink will be safe.

Freshwater quality and quantity in some Canadian regions may be more challenged in the future due to climate changes, industrial and agricultural developments, and population growth. Because of little understanding of the water ecology and various interests in the usage of water, it may seem that we have enough water sources and that we will always find other sources of water for drinking. While a dry country like Australia has to carefully manage its water sources, it is quite often that we take them for granted in Canada, for it seems we have far more than what we need.

Water quantity is indeed important, as limited resources are more quickly polluted by human activity, but excess water quantity does not assure safety. Many current industrial and even agricultural practices produce water pollution that exceeds the self-cleaning capacity of water sources (which is why we need to treat drinking water even in the absence of direct sewage disposal). Fecal pollution that follows human and animal presence also often exceeds the dilution capacity of a water body. While we may have more water sources than most countries in the world, if we do not take measures to protect them we may end up only having more contaminated water sources. As for production of drinking water by desalination of sea water, this is only available to ocean side communities, it consumes much energy and it has its own by-products that may accumulate. Therefore, as noted above, water source protection remains the best guarantee that we will continue to have safe drinking water in the future. This should take precedence over any other priorities related to water use.

"Water and Sanitation is one of the primary drivers of public health. I often refer to it as "Health 101", which means that once we can secure access to clean water and to adequate sanitation facilities for all people, irrespective of the difference in their living conditions, a huge battle against all kinds of diseases will be won." (Dr. Lee Jong Wook, Director-General, World Health Organization WHO 2004b)

4.1.1.2. Water is an important health determinant. Unsafe water is an important contributor to the global burden of disease.

Water has been documented by the World Health Organization among the relevant determinants of health based on the review of best available evidence (WHO 2005b).

An original estimate for 1990 reported in the Global Burden of Disease study (Murray and Lopez 1996) examined 'water, sanitation, and hygiene' as a risk factor in terms of the partial contribution to diarrhoeal and selected parasitic diseases. It was found that the worldwide disease burden from this risk factor accounted for 5.3% of all deaths and 6.8% of all Disability Adjusted Life Years (DALYs). DALYs for a risk factor represents the years of healthy life lost due to exposure to that risk factor. It incorporates both the years of life lost due to premature mortality, and the years lived with disability for incident cases, weighted proportional to the severity of the disability.

Studies done by the World Health Organization have also documented that improving access to safe water can significantly reduce morbidity due to a variety of waterborne diseases, even in the absence of other quality of life improvements (WHO 2004b). For example, the simple use of household water treatment in a community (such as chlorination) can reduce diarrhoea morbidity in the population by between 35% and 39%.

Another study used a linear regression model to evaluate the impact of several quality of life variables, including access to safe drinking water, to life expectancy at birth (Gulis 2000). Access to safe drinking water was found to be a statistically significant variable, being responsible alone for 9.42% (4.85-13.98) of overall life expectancy.

Many of the disastrous water safety situations that occur in less developed countries are not likely to happen in Canada. This is the result of many developments in water treatment and waste treatment technologies and of many years of public health work that have reduced the population pathogen burden. It is important however to note that maintaining this quality of life requires continuing commitment to disease prevention, including management of drinking water safety. We cannot simply rest on our laurels. Complacency can reverse this positive trend, and tragic events such as Walkerton are a painful reminder of that reality. We have to continue striving for the best as we consider future population growth, agriculture and industry growth, and climate challenges. What heritage we leave to our children depends on what we do in the present.

4.1.1.3. Drinking water should be safe and aesthetically acceptable to consumers.

Given our high standard of living, the Canadian public rightfully expects their drinking water to be completely safe. This has been the standard in the field of drinking water for many years, and it can continue to be so in the future. However, what we mean by safe is rarely defined (Hrudey 2005), and the public may have different understanding and expectations. Safe should be defined as representing a health risk so small that it can be easily ignored in comparison with other health risks in life. Safe is not absolute zero risk, which is unachievable. The part of the public that regards safe as being something that you do not need to worry about for your health, can be comforted that this standard of safety is achieved in Canada the vast majority of time.

Sometimes, however, the concept of safe may lead to an expectation of absolute zero risk, expecting the water they drink to be absolutely free from any possible and conceivable risks to health. Such an expectation is unrealistic (O'Connor 2002b; Hrudey 2005), but it can do a lot of harm in terms of misdirected resources and public stress.

While the impossibility of absolute zero risk may be accepted, setting safe water goals to zero risk is tempting, and it is already reflected for example in many U.S. EPA risk assessments for drinking water contaminants (i.e. MCLG=0). Such intention is clearly laudable per se, but may create problems when setting priorities for drinking water system upgrades and use of limited resources. It may lead to the pursuit of zero risk, quite often set for contaminants that are not documented as being harmful at the usual drinking water concentrations with any level of confidence, at the expense of more immediate and more effective measures that would limit risks for pathogens, e.g. multiple safety barriers.

In addition, as noted in Hrudey (2004), "a blind pursuit of zero risk may simply increase other risks". It is noted that consumer concerns over possible chlorination by-products have led to less efficient chlorination, a leading cause for several waterborne outbreaks presented in Hrudey and Hrudey (2004).

For this reason, I recommend that the distinction between safe drinking water and zero risk drinking water be made clear to consumers, using careful risk communication techniques. The public is entitled to expect that drinking water does not significantly add to their daily health risks. But it cannot expect to be completely, absolutely safe, as even the air they breathe in the cleanest environment and the food they eat is not up to such standard. Even if zero risk can be attempted for contaminants in drinking water that seem to recognize a toxicity threshold based on current science (e.g. selenium, cadmium), it is better to focus first on securing safe drinking water for everybody.

Secondly, the public does not have expert means to judge if their water is safe. Their only indicators are the colour (and clarity), taste and odour of the water they drink. In order to maintain public trust, water has to be aesthetically pleasant in addition to being safe.

It may be argued that aesthetically objectionable water is not necessarily a health risk, and indeed it may not be, and thus not a priority in drinking water production. However, aesthetically unpleasant water is sometimes a true indication of a water health risk, so water that "seems" unsafe will influence consumers to seek for other drinking water sources that may be more unsafe and less controlled for safety. One of the questionnaire respondents pointed out that, in his/her opinion as a field inspector, the bottling water plants in his area are far less concerned with water safety than municipal water operators. Also, using other sources of water (e.g. private wells) may lead to less safe water than municipal water.

Therefore drinking water should be both safe (as defined above) and aesthetically acceptable to consumers.

4.1.1.4. As the only agency that has population health as its primary concern, public health agencies should be major players in the field of drinking water safety.

Unsafe water is an important contributor to the global burden of disease. This is fortunately not the case for Canada or Australia, but it shows the importance that providing safe water has on population health. Assuring drinking water remains safe is thus primarily a public health responsibility. From population health perspective the management of drinking water safety represents an excellent example of primary prevention. Moreover, as suggested in Wanke et al. (1996) with application to drinking water safety (one of the environmental health sub-programs evaluated in the study), the public health sector has an unique role among various stakeholders involved in this area. While other sectors may contribute to safe drinking water, no other sector has population health as its primary concern. Public health is generally regarded by the public as the most competent, reliable and unbiased source of information for their health and safety concerns. This view was expressed by Canadian and Australian public health professionals on several occasions in our interviews and questionnaires, and confirms previous findings of University of Alberta researchers based on public focus groups, interviews and surveys with non-health senior government officials and public representatives (Wanke et al. 1996).

While some provincial/state governments have moved towards placing public health in a leading position in the field of drinking water (e.g. British Columbia, Canada; Victoria, Australia), at a minimum public health should have a strong enforcement capability and be a major player in the development of strategic planning and best management practices for this sector.

Environmental health strategies, in general, and drinking water safety, in particular, should be based on the same population health principles that are applied in any other public health area. In the environmental health area we now benefit in Canada from decades of work to prevent environmental pollution to becoming an important cause of disease. For example, for waterborne diseases via drinking water, we have already developed mechanisms to control pathogens the vast majority of the time (i.e. water treatment and disinfection). We do not always have such a favourable situation in public health with other modes of transmission for communicable diseases (airborne infectious diseases, sexually transmitted infections, etc.). We expect and we try to assure that drinking water is never a vehicle for pathogens. From a population health perspective, this represents a primary prevention strategy (Hrudey 2005). However, due to the rarity of waterborne disease in Canada, the efficiency of such interventions are unlikely to be reflected in public health surveillance (Hrudey 2005).

Some may argue that engineering interventions are not primary prevention. It may be objected that there are major differences between health promotion or immunizations, and the technical challenge to produce clean drinking water. After all, this is how drinking water production tends to be regarded by many uninformed people.

I believe this is more a matter of perspective, i.e. you can either chose to see the differences or may chose to accept the similarities. Indeed, engineering is very important for drinking water production. Cleaning source water is first an engineering challenge. But this means confusing the means with the objective.

The objective is to assure that drinking water from the tap will not make one sick. We immunize because we want to prevent people from getting sick from pathogens in their environment that may enter their body by various means. We promote sexual education and protections to prevent the spread of sexually transmitted infections. Along the same line we could, of course, vaccinate everybody against common pathogens present in water. We still do that for some pathogens, particularly when travelling to countries where people are more likely to get in contact with these pathogens, including via drinking water (e.g. hepatitis A, typhoid, cholera). But fortunately, we do not have to do this routinely in Canada. For drinking water we are actually able to interrupt the pathogen transmission cycle before it reaches a potential human host. We can intervene between the source of pathogens (human or animal) and the potential host and control transmission. By cleaning the water we provide in fact one less exposure pathway to pathogens. This is excellent primary prevention in public health.

Adopting the proper perspective assures that we do not lose sight of where our true priorities lie regarding drinking water. If we keep population health paramount, then delivering safe water is more important than mere economical considerations to make drinking water cheap (like for most non-essential goods and services).

Moreover, drinking water safety allows us to go much further in primary prevention than we can usually do for other pathogen transmission routes. As will be presented below in this section, in order to prevent waterborne diseases we can move more upstream to place more barriers that prevent pathogens from entering the water, rather than only fighting to remove them once they get in the water.

4.1.1.5. Drinking water safety strategies should be developed based on population health objectives.

According to the Public Health Agency of Canada, "Population health is an approach to health that aims to improve the health of the entire population and to reduce health inequities among population groups." (PHAC 2002)

Like any other population health interventions, drinking water safety strategies should be designed and implemented following population health objectives. The paper by Saunders et al. (1996a) is a good reference for the development of such objectives for environmental health programs in Canada, and can be directly translated for drinking water safety programs. A similar approach is introduced in WHO (2004a) for a worldwide audience.

Approaches based on outcome objectives are not new, particularly for drinking water delivery in large municipalities. Drinking water operation was traditionally based on such an approach, which is reflected in the large emphasis placed on water monitoring as an indicator of water quality and safety. Such objectives, usually called drinking water guidelines or standards, are in principle derived from a formal and comprehensive health risk assessment for particular drinking water contaminants.

However, accepting drinking water safety as a population health primary prevention strategy requires a clearer and more structured population health approach. More specifically, health based objectives will have to be developed for drinking water safety programs that allow them to be implemented and evaluated in a manner more consistent with other programs in the field.

The paper by Saunders et al. (1996a) can assist to this task. The paper details the development of outcome, process and structure objectives. Health outcome objectives are particularly of interest in this case, and a few remarks need to be made regarding their use. As noted in WHO (2004a), health status objectives as used for other population health programs are only useful for drinking water if epidemiologically detectable changes in population health status can be measured following the introduction of a specific drinking water safety intervention. The paper by Simmons et al. (2001) represents an attempt to extrapolate the risk assessment framework for chemical hazards to microbial health risk assessment for rainwater systems in Australia, and outlines the role of epidemiology to address some of the uncertainties. However major uncertainties at every risk assessment level prevent the use of such approaches at present time.

As explained in Hrudey (2005) and in Saunders et al. (1996a), the applicability of such an approach is limited in Canada because of various reasons: multiple exposure pathways and low burden of disease from contaminated drinking water for microbial contaminants, long lag periods and multiple aetiologies for diseases involving chemical contaminants. The result is that measurable population health impacts are likely to be statistically insignificant in most cases. Because of these reasons, the efficiency of drinking water programs or of individual systems is thus not generally amenable to evaluation based on health status objectives (with the exception of very localized drinking water safety issues, e.g. natural high fluoride concentrations in water, or very poor communities). The same applies for the timely recognition of waterborne outbreaks by public health surveillance. Adopting a population health perspective can however encourage research into the suspected carcinogenic effects of chemical contaminants in drinking water; health status objectives could be developed if statistically significant correlations are detected in the future.

Rather, risk assessment based *intermediate* targets should be employed for drinking water safety strategies. More specifically, according to Saunders et al. (1996a), risk-reduction objectives can be used on several levels across the chain of hazard transmission. Applying their framework, finished water quality standards followed by source water standards would be first level targets, the presence of drinking water safety barriers or preventive measures in a source to tap approach would be on the second level, and operational monitoring standards to assure that safety barriers are maintained would be the third level. Such objectives are more easily measurable and would provide a far better picture of the drinking water safety situation than health status objectives.

The above framework can be further applied to drinking water safety strategies by recording drinking water safety failures and near failures (for example, by maintaining a drinking water safety incident surveillance database similar to communicable diseases), and public satisfaction indicators (e.g. water quality complaints).

Process indicators can also be defined in a source to tap risk management approach that assures the high risks are addressed with priority. And structural indicators can be developed for relevant structural elements (e.g. legislation, staffing, information resources).

This approach can be further developed into a total quality management framework, as presented below in this chapter.

4.1.1.6. The clearest health risks to consumers of drinking water are posed by microbial contaminants.

A large volume of evidence supports the observation that microbial contaminants were and remain the greatest source of concern for drinking water safety. Drinking water safety barriers and preventive measures introduced since the end of the 19th century were specifically designed for and targeted biological pathogens. They represented a large step in the improvement of population health in the countries that introduced them, including Canada (Raucher 1996; Hrudey 2005).

Beginning with the 1970s, an increased interest in the study of toxic chemicals and technological advances in chemical analysis have lead to the identification of various chemical contaminants in drinking water (Raucher 1996). While for very few of these chemicals we can, even at present time, make a compelling case for being a population health problem (e.g. arsenic), their detection generated a lot of public anxiety reflected then in regulatory approaches targeted at limiting their presence in drinking water. Because of the perceived risks of chemicals, biological contaminants received then comparatively less attention in the scientific and technological research in affluent countries, possibly because they were no longer considered a serious problem in these countries due to the already existing water safety interventions (Raucher 1996).

This biased perception of risk towards chemical contaminants in affluent countries was lately challenged by several waterborne outbreaks, some of which also included human fatalities, e.g. Milwaukee 1993, Walkerton 2000 (Raucher 1996; Hrudey and Hrudey 2004). The common belief that chemical contaminants are a chronic, long-term, health concern, whereas microbial contaminants present only an acute health risk is also challenged by follow-up studies on former Walkerton outbreak victims that find increased risk of hypertension and reduced renal function, positively correlated with the severity of clinical symptoms at the time of the outbreak (Garg et al. 2005). Of course, microbial contaminants remained the primary focus for water safety interventions in low income countries all this time, since they are still an important contributor to the overall burden of disease in these countries (Murray and Lopez 1996; Pruss et al. 2002; WHO 2004b; WHO 2005a).

The importance of microbial pathogens as the most serious concern for drinking water safety is reflected in many sources of information. The reference base that supports it is too large to be completely presented here. Recent waterborne outbreak surveillance data (where available) support the same conclusion. For example, in the most recent Morbidity and Mortality Weekly Report (MMWR) Surveillance Summaries (Blackburn et al. 2004) published by the U.S. Centers for Disease Control and Prevention (CDC), an estimated 981 out of 1020 persons involved in the 31 waterborne disease outbreaks in U.S. reported between 2001-2002 were sick due to microbial agents, and none of the seven deaths reported were due to chemical contaminants.

The same idea is reflected in more recent environmental health textbooks (Yassi et al. 2001; Moeller 2005) and in the rationale of some of recent drinking water safety strategies (NZMOH 2002; CCME 2004; NHMRC 2004a; WHO 2004a) or reports (Raucher 1996; Hrudey 2005). However, other references may not be very clear on this priority (Koren and Bisesi 1996).

Unfortunately, this conclusion was not obvious to all interviewees and questionnaire respondents in the study. For example, while 76.7% of all valid questionnaire responses correctly identified microbial contaminants as the most important concern for drinking water safety (question 6), a substantial fraction nevertheless pointed towards chemical hazards (including disinfection by-products). Moreover, public concerns for drinking water safety as reported by questionnaire respondents (question 5) reflected the same lack of clarity on priorities (many concerns on disinfection by-products and other chemicals and only 56.7 % concerned about microbial safety), despite coliform testing being the first water safety test recommended by the public health agency.

For microbial waterborne diseases we generally have the advantage to easily recognize the causal agent, although linking it to drinking water may not always be a straightforward process. The same does not generally apply to chemical agents, often suspected to cause diseases that recognize multiple aetiologies (e.g. cancer). In addition, most microbial diseases are acute, whereas diseases where chemical contaminants are suspected to be involved are often chronic and/or have long latency (e.g. cancer, reproductive effects). This situation may rightfully be suspected to introduce a surveillance bias towards biological agents.

However, health risk assessments based on the current body of knowledge (toxicology and, where available, epidemiology) do not indicate large health risks at low environmental levels. Many drinking water guidelines for chemicals are very conservative, with large margins of safety. Indeed, for most environmental chemicals their role in human sickness remains largely an assumption. By contrast, the burden of disease by microbial pathogens in drinking water has been well documented, with clear aetiology.

Disinfection processes that control pathogen presence in drinking water should never be compromised for other considerations, including that of formation of disinfection by-products (DBPs) (Ashbolt 2004; Hrudey 2004; Hrudey and Hrudey 2004; NHMRC 2004a; Hrudey 2005). A risk assessment model has been developed by Ashbolt 2004 to provide a quantitative basis for this recommendation.

4.1.1.7. Small water systems (community and private) present the greatest concerns for drinking water safety.

The majority of interviewees and questionnaire respondents identified small water systems as presenting most concerns from a public health perspective. The concerns were most often related to microbial contamination of drinking water. By contrast, large municipal systems were generally considered safe most of the time, due to the presence of multiple safety barriers and regular water monitoring. Concerns for large systems, when present, related more to chemical contamination or disinfection by-products, although protozoan contamination was also mentioned (*Giardia*, *Cryptosporidium*).

Public health concerns surrounding small water systems (private, communal or small municipal) are not new (WHO 2004a). In fact, Walkerton was precisely such a system. The Report of the Walkerton Inquiry – Part 2 (O'Connor 2002b) dedicates an entire chapter to small systems and notes their particular problems. Conclusions were based, among others, on an expert assessment of Ontario water supplies that noted several important deficiencies, specifically Geldreich and Singley (2002). Similar observations were made by the participants in our study.

Box 4 - Yukon Territory waterborne outbreak

The book "Safe Drinking Water" (Hrudey and Hrudey 2004) among other small system examples, presents a case of a restaurant/motel complex in Yukon, situated on Alaska highway, that became the source of a viral gastroenteritis outbreak among bus passengers stopping for lunch during the summer of 1995, with 433 estimated primary cases, due to a contaminated water system. While the investigation and identification of cause in this case is remarkable, it is also the likely result of somewhat special circumstances (the diverse locations and itineraries of travellers facilitated triangulation to the most likely location), and it is quite likely that many more such places would go unnoticed for many years, infecting unknown numbers of innocent travellers.

In summary, the problems that confront small water systems are: lack of safety barriers or efficient barriers that can withstand pathogen challenges (especially protozoa, but also viral and bacterial), often outdated (if any) treatment, limited financial resources, limited capacity to monitor water quality or system operation, often lack of interest in water safety by both operator and the community, widespread lack of operator competency, and sometimes lack of public awareness reflected in a consumer belief that water is safe even in spite of adverse bacterial results.

Because of serving limited numbers of people (or mostly non-residents in the case of motel, restaurant or park water supplies) these systems are unlikely to affect a large number of residents if their water is unsafe. In addition, by serving the same water all their life, residents tend to develop some level of resistance to common pathogens in their water. For these reasons, small systems rarely get noticed by locals for making people sick despite their deficiencies, which contributes to the consumer perception that their water is safe. However, the same may not apply to non-residents (lacking immunity to local drinking water pathogens) or to vulnerable populations like children, elderly, or immunocompromised.

Lack of public awareness and of financial resources were often cited as major reasons for small system deficiencies. However, access to safe water should be provided to all Canadians, regardless of their location. In this spirit, the Walkerton Inquiry report – Part 2 (O'Connor 2002b), while noting difficulties for small water systems, points out that drinking water delivered by these systems still has to be safe, and this cannot be compromised by any financial considerations. This is consistent with an ethical population health approach based on equity.

In fact some interventions can be applied to improve the situation of small water systems without substantial resources. A few suggestions will be presented below in this chapter. In addition, many small water system problems can be resolved by expertise outreach from large municipal systems, regionalization of water systems, or simply connecting to the adjacent municipal systems.

4.1.1.8. Water system operators are public health professionals.

There are generally no expectations at present time for operators responsible for small, unregulated water systems to have any formal training, let alone certification. This is probably one of the most underestimated sources of concern for public health. After all, we wouldn't conceive to have untrained physicians or nurses taking care of patients, in all but the most extreme emergency circumstances. We wouldn't limit the number they can treat to 15; we would simply not want them anywhere near the patients, in order to prevent accidents due to incompetence. Why should we then hand out the responsibility of producing and delivering drinking water to untrained individuals? Unsafe drinking water can make a lot of people sick and it has also killed in the past. Enforcing formal training and certification would better protect public health and would also empower operators to make more intelligent choices and be able to advocate for affordable and safe water systems in their community.

The Walkerton Inquiry report – Part 2 (O'Connor 2002b) emphasizes the crucial role of water operators in protecting the safety of drinking water. Training to enable them to adequately protect population health is recommended. It is also recommended that municipal water operators be held "to a statutory standard of care", similar to other health professionals. Recommendations were based on expert testimonies, including an expert assessment of Ontario water supplies (Geldreich and Singley 2002), as well as on conclusions resulting from witness testimonies during the inquiry. Specifically, in the Part 1 of the Walkerton Inquiry Report (O'Connor 2002a), Justice O'Connor states (p.17): "Although Mr. Koebel knew how to operate the water system mechanically, he lacked a full appreciation of the health risks associated with a failure to properly operate the system and of the importance of following the MOE requirements for proper treatment and monitoring". This was a key finding in the inadequacy of water operator training in Ontario. Subsequent expert assessments revealed that such lack of understanding is quite common among small system operators (Geldreich and Singley 2002). Clearly, water operators need to have some level of public health training to understand the purpose of the regulations they have to follow.

The interviews and questionnaires administered in the study reveal that this situation has hardly changed for small water systems across Canada, three years after the publication of this report. Judging from the interviews and questionnaires in the study it seems that in some provinces public health has limited to negligible input in water operator training. This is understandably a consequence of safe drinking water provision being regarded as a technical challenge and not a population health intervention. Safe water provision is, and should be regarded as, primarily a public health issue. Therefore, at a minimum, public health expertise should be invited to input into all levels of water operator training, for both small and large systems.

As public health professionals, water operators must maintain a sense of responsibility to the public and be able to understand, appreciate, and effectively respond to water system challenges. As such, they need to be well-trained to understand their system from source to tap, and be involved in the development of risk management plans for their system.

Furthermore, to assure drinking water safety, training is necessary for operators of every public water system regardless of size. It may seem expensive for small system operators, but in fact it costs much less than having to deal with consequences of an outbreak.
Moreover, by emphasizing source protection and other preventive measures that prevent contamination, it would be a better use of resources to protect population health than weekly finished water bacteriological monitoring. The benefits of a proactive, source to tap risk management approach to water safety will be presented below in this chapter. Such process would also empower and engage operators to take a more responsible role towards their water system operation.

While operators receive minimal training to be able to competently perform their duty, organized expertise has to be made available to support them in more difficult situations. For example, many remote communities in Canada are served by nursing stations where personnel can get advice and support from larger centers. A similar service should be considered for small unregulated water systems.

4.1.2. Principles for management of drinking water safety

4.1.2.1. Source water should never be presumed safe because it may always be subject to fecal contamination.

Source water should never be presumed safe since it may always present fecal contamination. The most important source of disease via drinking water has long been documented to be human and animal waste (NZMOH 2002; Hrudey and Hrudey 2004; NHMRC 2004a; WHO 2004a; WHO 2004b; Hrudey 2005). As long as these sources of pathogens can reach the water, no source water can be presumed safe. Active intervention to assume safety for human consumption is thus always necessary.

As such, no surface water can be kept entirely free of risk. For many water sources used for drinking water, contamination is unavoidable. Wherever you have people there will be human and often also animal waste (pets and/or livestock). Even remote, seemingly pristine waters may be contaminated. The risk of waste entering the water is still there, if only from wild animals and occasional trespassers. The same logic applies for groundwater under direct influence of surface waters.

As for groundwater in, for example, confined aquifers, the water is in principle more protected from such contamination. However the hydrogeology can change or accidents can happen; for example, an aquifer used for water abstraction can become contaminated by infiltration or human intervention (e.g. drilling). Even continued periodic monitoring with negative results to prove that a water source is safe does not provide any guarantee that a previously clean water source does not become contaminated.

Box 5 - Washington County Fair waterborne outbreak

According to Hrudey and Hrudey (2004), in the Washington County Fair waterborne outbreak none of the wells used during the event (including the well suspected to have been the source of microbial contamination) had any monitoring failure prior to the outbreak. However, the incriminated groundwater well was too close to a septic tank tile field and it became contaminated with *E.coli* O157:H7 and *Campylobacter jejuni*, resulting in an estimated 2,800 to 5,000 cases of gastrointestinal illness (based on a random telephone survey), 71 hospitalized patients, 14 cases of hemolytic uremic syndrome, and two deaths.

The latest MMWR Surveillance Summary (Blackburn et al. 2004), based on voluntary reporting from public health agencies in U.S. states and territories, notes that 40% (10 out of 25) of drinking water outbreaks in U.S. in 2001-2002 were due to untreated groundwater systems. The proportion is not much different from the previous Summary: 43.6%, or 17 out of 39 (Lee et al. 2002). The results are likely underestimated, because not all waterborne outbreaks are recognized, investigated or reported, particularly as it relates to small systems where the relatively low number of cases may not reach statistical significance against the background of enteric infections. Since there are no reasons to assume that an increase in source water quality accounts for the reduction in absolute numbers of outbreaks, the only surprising element remains that the lesson does not seem to be learned, i.e. every water source needs treatment.

The book "Safe Drinking Water" (Hrudey and Hrudey 2004) presents several cases when the belief in the safety of untreated water has been proven wrong by a waterborne outbreak incident. However, according to some interviewees and questionnaire respondents, this is a major impediment to implementing water safety barriers for small water systems in some areas of Canada, where the public is convinced that their water is naturally safe. A similar case has been thoroughly documented by a PhD candidate in a risk communication naturalistic research project in relation to the implementation of the EPA Safe Drinking Water Act by county health officials in a small town in U.S. (Word 1998). This illustrates the importance of risk communication in the success of drinking water safety interventions to protect population health (see principle 4.1.4.5).

In addition, as will be presented below, water monitoring is limited as a sole indicator of water safety, particularly water that is rarely contaminated.

4.1.2.2. Management of drinking water safety should be a proactive rather than a reactive process.

Being proactive is what population health is all about. For primary prevention in particular, we do not expect a disease to strike; we take measures to reduce the risk of pathogens being able to inflict harm on susceptible hosts. The same principle should be followed for drinking water. Management of drinking water safety is an exercise in environmental health risk management, not in compliance monitoring. In other words, we should not wait to see if pathogens have broken into the water that is distributed to consumers before taking public health action. What we have to do is place preventive measures and safety barriers that would assure the water does not get contaminated in the first place. The more upstream we can place preventive measures, the more barriers we would set in the pathogen transmission cycle, and the more time we will have to detect pathogen breakthroughs and take corrective action. This is a far better guarantee to safety than reactive approaches based on compliance monitoring for finished water.

Interviews and questionnaires have revealed that a prevalent belief among public health professionals is that public health protection consists in monitoring drinking water quality results and if they indicate contamination, then a boil water advisory can be issued to prevent consequences to consumers. Believing in the efficiency of this approach not only neglects the low diagnostic sensitivity of pathogen monitoring (Allen et al. 2000), and assumes 100% public compliance with the advisory, but also disregards the fact that by the time the results come, contaminated drinking water has entered the distribution and often has already reached consumers (NZMOH 2001; Hrudey 2004; NHMRC 2004a). In fact, a common pattern that can be noticed in many of the outbreaks analysed in "Safe Drinking Water" (Hrudey and Hrudey 2004) is that boil water advisories are typically issued near the end of the outbreak. Thus, while such approach may be effective in limiting the extent of an outbreak, action will often be taken after consumer exposure to contaminated water has already occurred and will not assure illness prevention in the population.

As such, compliance monitoring to satisfy numerical drinking water guidelines is inherently reactive. It is much better to work in preventing another Walkerton tragedy, than to deal with its consequences after it has started. Therefore, a true primary prevention approach has to move upstream from the current focus on compliance monitoring.

In addition, compliance monitoring has other important limitations as a water quality control measure.

First, finished water monitoring results cannot be very representative for the quality of drinking water delivered to consumers (Allen et al. 2000; Hrudey and Hrudey 2004). 200 millilitres or even one litre of water collected for analysis cannot be very representative for the megalitres of water that pass through many systems, even if done daily (although weekly frequency is usually the case for small water systems). Pathogens in drinking water, if present, are not likely to be homogenously distributed. Rather they would be present in clumps, attached to particulate matter (Hrudey and Hrudey 2004). Finished water monitoring tests thus have low diagnostic sensitivity, so they are highly uncertain as to the true quality of water monitored and may produce many false negative results (e.g. coliform negative results). As such, end-of-pipe water monitoring is prone to encourage unwarranted complacency and an under-estimation of actual drinking water safety breaches.

Second, compliance monitoring is even less reliable to accurately predict the presence of rare but important health hazards in order to be able to guarantee the quality of drinking water (Allen et al. 2000; Hrudey 2005). In the case of media where hazards are rarely present (e.g. finished water), the opposite may happen. Intense pursuit of unlikely environmental hazards can in fact often produce positive evidence although the contaminant is not truly present (i.e. false positive results). (Hrudey and Leiss 2003; Hrudey and Rizak 2004). No analytical method for water contaminants has 100% diagnostic specificity. Thus, for rare hazards, it is likely that true positives will be greatly covered by false positives, lowering the positive predictive value to insignificant levels from a risk management perspective. As pointed in the section 3.2., this is an inherent limitation and not something that can be greatly improved by sampling or analytical techniques.

Third, the issue is even further complicated by pathogen variables such as infective species and viability. Laborious analyses may sometimes be required to evaluate if the particular species present is the one affecting humans, and to check if respective biological contaminants are viable. This is not information that can be obtained readily, and it can generate false alarms. This is suspected to have been the case with the Sydney *Cryptosporidium* crisis in 1998 (Hrudey and Hrudey 2004).

Being inconsistent and little representative, such results intuitively encourage scepticism in experienced operators and regulatory representatives, which in turn leads to inertia and delayed intervention. Occasionally, the opposite may happen, particularly for unusual contaminants: exaggerated, knee-jerk responses.

During our study, some interviewees and many questionnaire respondents failed to recognize some or all of these limitations of finished water monitoring. Unfortunately, finished water monitoring is often regarded as a reliable control measure even in the absence of other water system data. The reasons may stem from a lack of understanding of its limitations, a belief that it is the most cost-effective control or simply because there is rarely health surveillance data to either support or contradict water monitoring results. As presented above, it is hard to make a case for water monitoring results as being very representative for the quality of water delivered to consumers, in the absence of other corroborating evidence. As for cost-effectiveness, source protection is less employed although often it would be far more effective and less resource consuming (see below in the chapter). And, as presented in the above principles, unsafe water systems will rarely be reflected in detectable health surveillance data in the population, which do not provide reliable assurance that the water was truly safe.

Concerns are often driven by what is tested. In practice this means that the results of bacteriological tests tend to draw most of the public's attention, becoming a Catch 22 situation (that public health actions in turn would focus mostly on keeping these adverse results to a minimum, and reinforce them as the sole indicator of drinking water safety). Thus, while the emphasis on bacteriological pathogens is desirable, the focus of the drinking water safety strategies as well as the public concerns on bacteriological monitoring of finished water is not, since it promotes a false sense of security (i.e. as long as water monitoring results show nothing of concern, water safety seems guaranteed).

Because of the reasons mentioned above, drinking water safety for a water system is better assured by developing a risk management plan based on a system-specific risk assessment process (as detailed below in this chapter). Controls can then be based on the use of proxy ("intermediate") monitoring standards linked into the plan and based on risk management principles, than by the use of end-of-pipe monitoring (IWA 2004; NHMRC 2004a; WHO 2004a). They would have a much lower margin of uncertainty than current water monitoring, would indicate barrier breaches and allow for prevention, and would be consistent with the principle of "never assume water is safe" (4.1.2.1). The concept is similar to the establishment of population health targets, where outcome targets are less useful for management and evaluation than intermediate targets. To aim for the best, this is best translated in the development of a total quality management approach (see the principle below).

4.1.2.3. Management of drinking water quality should follow a total quality management approach based on risk management principles.

Total quality management (TQM) is defined in many ways. A simple Web search provides over 20 definitions, among which are:
"An approach to business management that focuses on quality and typically has: a strong customer orientation, total involvement, measurement systems, systematic support, and continuous improvement."
"The application of quantitative methods and human resources to improve the material and services supplied to an organization, all the processes within an organization, and the degree to which the needs of the customer are met, now and in the future."
"A product-quality program in which the objective is complete elimination of product defects."

The TQM approach is a commitment to product quality and doing things right the first time, instead of reacting to problems. It has customers as its central focus and a commitment to continuous improvement of quality of service. The approach is based on defining internal processes and developing indicators and controls to assure that each relevant process maintains the necessary performance and quality, in order to assure the quality of the final product. This approach has been implemented in many areas of production and services, including in the U.S. federal government.

These characteristics of the TQM approach make it particularly useful for management of drinking water. The primary focus on customers (i.e. public) is similar to population health interventions, primarily focused on the population they target, and introduces the correct order of priorities for drinking water safety. Based on the risk management approach to drinking water safety, several internal processes can be identified: watershed management, source water protection, storage reservoirs and intakes, treatment (with sub-processes), disinfection (with sub-processes), service reservoirs, distribution systems, private internal distribution (e.g. buildings), customers. The TQM approach does not only include technology, but also people responsible for the management and operation of the system. And finally, the continuous commitment to service improvement is necessary to maintain customer confidence (more about this below).

The Part 2 of the Walkerton Inquiry Report (O'Connor 2002b) advocates a quality management approach for the Ontario municipal water systems in order "to protect public health by achieving consistent good practice in managing and operating a water system" (p.336). Adaptation of this approach to drinking water systems would include:

- the adoption of best practices and continuous improvement;

- “real time” process control (e.g., the continuous monitoring of turbidity, chlorine residual, and disinfectant contact time) wherever feasible;
- the effective operation of robust multiple barriers to protect public health;
- preventive rather than strictly reactive strategies to identify and manage risks to public health; and
- effective leadership. (O'Connor 2002b)

Hrudey (2004) notes in this context that “The emphasis on systems that seek to assure that processes are functioning as designed is intended to achieve a preventive rather than a strictly reactive approach to assuring quality”. Thus, the TQM approach presents a practical approach to achieve the previously developed principle in this chapter, i.e. that management of drinking water safety should be a proactive process, consistent with true primary prevention in population health.

Hrudey 2001 introduces ten risk management principles for drinking water safety that I will refer to at several points in this chapter. The theme is re-evaluated again (Hrudey 2004) benefiting from the experience from participating as expert in the Research Advisory Panel for the Walkerton Inquiry, into six principles that can best be reflected in the TQM approach:

1. Anticipate and prevent harm rather than just reacting to problems.
2. Set priorities based on risks rather than hazards.
3. Use risk assessment to inform risk management, seeking actions that will achieve the greatest overall reduction of risk.
4. Recognize the inevitable role of human behaviour; maintain vigilance and fight complacency.
5. Know your system and convert hindsight into foresight.
6. Seek leadership and invest in knowledge. (Hrudey 2004)

I will address these principles below in this section from a population health perspective.

Lastly, the TQM approach is advocated for Australian water suppliers in the most recent “Australian Drinking Water Guidelines”, under the “Framework for Management of Drinking Water Quality” (NHMRC 2004a). The framework has been adopted by the National Health and Medical Research Council (NHMRC) and is now being implemented by member states. Following on expert work in drinking water and approaches like the Australian TQM framework, WHO now effectively advocates a quality management approach to drinking water safety for a worldwide audience under the framework for safe drinking water, present in the last edition of the “Guidelines for Drinking-water Quality” (WHO 2004a).

While other approaches may be considered for management of drinking water safety, they need to be able to assure at least the same performance as the TQM approach, i.e. to constantly produce water of the best quality.

4.1.2.4. Drinking water systems should be designed in response to a system-specific, source to tap, risk assessment process.

Understanding your water system, the health hazards present and their sources, and the risks that they present to the health of your consumers allows making the best informed decisions about preventive measures and safety barriers that should be included in your water system. Thus, a system-specific risk assessment should be performed for every new water system, and also before planning improvements to an already existing system, regardless of their size. This allows the most practical, cost–effective use of resources that maximizes population health benefits.

While the risk assessment process for water supplies is developed in various ways by New Zealand (NZMOH 2001), Australia (NHMRC 2004a), and World Health Organization (WHO 2004a), its essential characteristics remain the same:
- know the system
- identify hazards and their sources
- estimate and prioritise risks
- plan preventive measures/ barriers for each risk
- plan how to monitor their performance and what corrective actions to use when needed
- document the risk management plan.

Having a system-specific risk assessment as a basis for your water system allows an effective use of resources and to prioritise operator activity to assure high risks are prevented first, and avoids wasting time and money for processes that address nonexistent or insignificant risks. Another result of the risk assessment process is that possible challenges to your system are recognized and emergency plans are developed before the incidents happen. It also allows operators to be more actively involved and understand their system and risks. This would address the common lack of knowledge that was noted in the previous principle (4.1.1.8). A "one size fits all" approach is doomed to be inflexible, wasteful of resources, fail to promote operator understanding, and may either be late or unable to respond to unusual challenges.

4.1.2.5. Management of drinking water safety should recognize that human error is unavoidable, and thus account for it in the planning of preventive measures.

People make mistakes all the time. While proper training should minimize their frequency, there can be no guarantees that even the most motivated and competent operator will not make a mistake at some point in time. The risk management plan for the water system is thus fundamentally flawed if unavoidable human errors can have serious public health consequences (Hrudey 2001; Hrudey 2004).

A good water system would thus design critical processes and use equipment in a manner that limits the consequences of an error. Better yet, where possible, water systems should have built enough redundancies to not allow the accidental failure of a barrier/preventive measure due to human error to have any major consequences on consumer health. This emphasizes the importance of multiple safety barriers principle (see 4.1.4.4.) as a measure to limit consequences in the case of barrier failure.

It is unrealistic to expect that any training or enforcement actions will improve human performance and completely exclude mistakes. In the absence of above mentioned measures, an enforcement-only approach is unlikely to assure the safety of drinking water.

4.1.2.6. Continual improvement is essential to maintain consumer confidence and to be able to respond to future challenges to drinking water safety.

Continual improvement is one of the mainstays of a total quality management approach. This process as applied to drinking water management would recognize several components.

First, addressing water system risks identified in the risk assessment process in the order of their magnitude (see 4.1.3.3.) according to a system improvement plan further reduces the risk of system failure to assure distribution of safe water to the public.

Second, drinking water management has to be continually adjusted to system changes and new sources of hazard (e.g. watershed developments). This can be achieved by regularly updating the system-specific risk assessment process and then the risk management plan.

Third, people learn by "trial and error". While the best knowledge that provides safe water in the vast majority of situations is applied to assure drinking water safety, it is impossible to foresee every conceivable hazard. However, there is also no need to allow the error to be repeated. The best approach to improving drinking water safety is to implement a formal system that allows yourself and others to learn from the experience of past failures, near failures or "close calls".

From a population health perspective, surveillance is an important part of primary prevention. However, in the area of drinking water safety we can do better than just learn from the tip of the iceberg (i.e. only from waterborne outbreaks that have been recognized, investigated and also reported). The value of a drinking water safety surveillance system can be sensibly improved by documenting water system failures and near failures. A truly population health preventive approach would thus include setting a formal system of incident surveillance, reporting system failures, near failures or "close calls" at a regional or provincial level. Expert support can then analyze each incident and draw lessons that can then inform and benefit all water suppliers in the area. Formally converting hindsight into foresight allows for efficient, rather than random learning (Hrudey 2001; Hrudey 2004).

Incident surveillance can be designed similarly to other population health surveillance systems like communicable diseases, and included into a larger water safety surveillance system (see principle 4.1.5.3.). For example, reporting of failures and near failures can be a development of the current water monitoring results surveillance databases initiatives already present in some regions.

In addition, several initiatives can be implemented at regional, provincial or national level to further promote drinking water safety:
- Research to validate water treatment process and preventive measures, and to identify and develop more efficient and robust processes and technologies. The limitations resulted from risk assessments and the analysis of past failures may assist in identification of priority research areas.
- Research conducted to identify, characterize, diagnose and develop preventive measures for new or emerging pathogens or other hazards (e.g. chemicals).
- Allocation of resources to review national and international research relevant to drinking water safety. This can be done for example at the provincial level, to inform and update water safety consultants within public health agencies.

Consumer confidence in their water system can be built by continual commitment to improvement, avoiding major system failures and learning from experience. Provincial governments can assist this effort by a number of initiatives, as presented in
section 4.1.5.

4.1.2.7. Safe drinking water can best be achieved by close co-operation and partnership with all stakeholders, including consumers, in a transparent fashion.

The risk management should be iterative, rather than linear, and should engage stakeholders in the process (Pollard et al. 2004). Safe drinking water is best achieved through partnership between all interested parties. The process of assuring safe drinking water recognizes several stakeholders: water operators, municipality, the licensing agency(ies) for water systems and waste disposal (if applicable, usually the Department of Environment local office), public health agency, other governmental agencies (e.g. food, agriculture, natural resources), businesses in the area and local community. The role and responsibilities of each stakeholder have to be clearly defined to ensure the complete coverage of issues, from source to tap.

Implementation of many preventive measures that can increase drinking water safety and reduce treatment costs depends on involvement of other stakeholders. The best example is probably watershed management, where quite often all above mentioned stakeholders can usually contribute.

Interviewees and questionnaire respondents in our study mentioned several areas where coverage of issues is weak ("grey" areas): watershed management; source protection from agricultural, industrial or other environmental hazards; small water systems where jurisdiction criteria (licensing, inspection) are difficult to interpret (trailer parks, private developments); regions with mixed aboriginal/non-aboriginal population, or Métis communities; industrial developments with their own water system; cross-connections with sewage systems, etc.

In order to assure drinking water quality, the Bonn Charter for Safe Drinking Water (IWA 2004) recommends (p.9): "The roles and responsibilities of the different institutions contributing to the delivery of safe and reliable drinking water need to be clearly defined and ensure complete coverage of the system from catchment to consumer. Governments should establish the legal and institutional arrangements necessary to assign appropriate responsibilities among the various parties."

While it may seem that many such issues get resolved by negotiation between stakeholders, in practice limited resources in various agencies can have the effect of leaving areas of drinking water safety with minimal supervision. In such cases it is usually the public health agency that has to fill the gaps, within the limits of their mandate and usually under the health hazard legislation in reaction to health incidents or public complaints. Such "grey" areas rarely benefit from proactive interventions since the responsibility does not clearly belong to any agency.

The Australian Framework for Management of Drinking Water quality includes community consultation (NHMRC 2004a) in its total quality management approach, in order to achieve co-operation and feedback from local community on issues affecting water quality. Canadian water providers would be well-advised to adopt a similar approach.

4.1.3. Risk assessment

4.1.3.1. Water system priorities should be based on the estimated magnitude of system-specific health risks rather than on the mere presence of hazards in the environment.

The environment presents innumerable potential hazards to human health. In theory, many of these can be present in drinking water. However, for a specific water system most hazards listed in the guidelines /standards for drinking water quality are unlikely to commonly be present in the watershed or source water, let alone treated water. Moreover, as elaborated in principle 4.1.1.6, many chemicals present in guidelines have not been conclusively proven to be harmful to human health. Even if they are, the guidelines have been developed considering life-time exposure of the most vulnerable population. Short-term exposure at respective levels is thus highly unlikely to present any risk to population health. The purpose of a water system risk assessment is to appreciate what true hazards can be present in the tap water at a level that they do represent a risk to consumer health.

In this context it is important to make the distinction between hazards and risks. “Hazard is the potential to cause harm. Risk is the probability that a hazard will cause harm” (Hrudey 2001; Hrudey 2004). The same articles also explain the difference between hazards and risks using *Cryptosporidium* as an example: While *Cryptosporidium* is a hazard in any surface water source, for a specific water system the risk of *Cryptosporidium* represents that probability that infective oocysts will pass through the safety barriers in sufficient numbers to cause infection in consumers.

The system-specific risk assessment process should follow the standard steps in risk assessment: issue identification, hazard identification, dose-response assessment, exposure assessment and risk characterization (enHealth_Council 2002). Therefore, the start of the system-specific risk assessment will be to list potential hazards and hazardous events for a water system and understand their sources. This process should then be followed by defining the level of risk that each poses to consumer health. Risk characterization for each hazard (or hazardous event) can be based on a combination of the likelihood of occurrence and the estimated magnitude of consequences if the hazard occurred (based on the predicted exposure level and the dose-response assessment at population level).

Risk characterization can be qualitative or quantitative. Because of the high uncertainties related to water system hazards (Hrudey 2001; NHMRC 2004a) a fully quantitative risk characterization for each hazard is unlikely to be very practical. To assist in prioritising specific risks for a water system, the Australian Framework for Management of Drinking Water Quality (NHMRC 2004a) provides a semi-quantitative matrix based on qualitative estimates of the likelihood of occurrence and the severity of consequences for each hazard if it occurred.

In existing systems some barriers already exist which lower certain water source risks. Because of this, it will be necessary to perform two risk assessments for every system:

- 'maximum risk' assessment, without considering existing barriers, to identify system-specific high risks for emergency planning;
- 'residual risk' assessment, after considering existing barriers, to assist in planning system improvements (NHMRC 2004a).

In the case of a new water system, the maximum risk assessment can be used to design the system so that it prevents high risks to assure a reasonable level of safety, and plan future improvements based on residual risk assessment.

4.1.3.2. Risks should be assessed at all points throughout the water system, from source to tap.

For the above described risk assessment process, risks will have to be evaluated at all points in the source to tap continuum. Hazards and hazardous events that result in unsafe drinking water can affect the water system at any level, beginning with the watershed. For example, a hazardous event can be a sewage spill in the watershed, but could also be a loss of pressure in the distribution system that may allow hazards to contaminate already treated water.

This principle applies for both risk assessment and risk management. It also applies to monitoring (CCME 2004; IWA 2004; NHMRC 2004a), where simple reliance on finished water monitoring promotes a reactive, rather than proactive approach to water safety, as well as other limitations, as presented in principle 4.1.2.2. By assessing risk at all levels in the system, preventive measures can be implemented and their efficiency monitored in order to prevent hazards from breaking into the system.

4.1.3.3. Furthermore, system-specific risks should be addressed in the order of their magnitude, starting with the very high risks.

As elaborated in principle 4.1.3.1., risk assessment should identify system-specific risks and prioritise them. Risks should then be addressed in the order of priority (Hrudey 2004; NHMRC 2004a). Preventive measures and barriers should address the very high risks first. Selection of critical control points, operational monitoring and drinking water quality monitoring should follow the same logic. Planning improvements should make use of the results of risk assessment, and strive to eliminate/reduce risks in the same order.

Risk-reduction can be achieved by the use of preventive measures (e.g. watershed protection) and safety barriers (e.g. filtration, disinfection). As pointed above the measures that prevent high risks to occur should be the first to be implemented, whereas low risks can be the object of future system improvements. For example, since every source water can present fecal contamination, the choice of the best protected sources and disinfection of water should be the first to be implemented. Filtration should also be implemented if possible, to prevent the passing of protozoan cysts resistant to disinfection.

Such measures should not be limited to water treatment, but rather should attempt to prevent risks as close at possible to the source, which is the best primary prevention in population health (this will be elaborated in the risk management section, at principle 4.1.4.1). In this context, the necessity of watershed management as a preventive measure was recognized by some interviewees. However, albeit being supported in principle by the Public Health Act, they often emphasized the limitations in practice of their mandate in this area.

The same logic should be followed for selecting critical control points. These are defined as (NHMRC 2004a): "an activity, procedure or process at which control can be applied and which is essential to prevent a hazard or reduce it to an acceptable level". Critical control points should be selected in order to control the very high hazards first. Similarly, operational monitoring should monitor the performance of key barriers to prevent high risk hazards.

For example, microbial contaminants represent a high risk for all water systems. In this case, an example would be chlorination and the monitoring of chlorine residual, which indicates effective disinfection and assures protection from susceptible pathogens in the distribution system. For pathogens not sensitive to chlorination, e.g. *Cryptosporidium* or other protozoa, post-filter turbidity level is an indication of effective filtration that removes most oocysts from source water.

The same priority should apply for drinking water quality monitoring. Monitoring should be oriented towards checking the presence of microbial pathogens. For chemical contaminants, monitoring should only be performed if the results of the risk assessment indicate a true risk from a chemical in the drinking water provided by the respective system. It does not make any sense to monitor regularly for a large list of potential hazards, if most of them are unlikely to be present (Hrudey 2005) (this will be elaborated in principle 4.1.4.3.).

It may seem reassuring to monitor finished water for any potential contaminants, but quite often this is just a waste of resources, while many interviewees and questionnaire respondents acknowledge that bringing small water systems up to date for microbial health risks cannot be done due to lack of resources. Population health can be better assured by implementing a preventive approach, as presented above in this section, rather than relying on compliance monitoring, whose limitations have been elaborated before.

Indeed less likely hazards may still occur in principle but, as noted in the conclusion of Hrudey 2004, we need to "seek to ensure that we do not fail to achieve the most important improvements in practice while we contemplate the universe of problems that could conceivably pose a challenge to drinking-water providers". The vast majority of waterborne outbreaks with serious population health consequences in affluent countries (Blackburn et al. 2004; Hrudey and Hrudey 2004) did not occur because of unexpected, exotic contaminants. Rather, they were caused by common and predictable pathogens, often because of insufficient prevention or lack of effective barriers.

4.1.4. Risk management

4.1.4.1. Measures to prevent contamination from entering the system are more effective and cheaper than complex water treatment and/or extensive water quality monitoring.

Investing in measures to prevent contamination from entering the system is more effective and cheaper than investing in complex water treatment and/or extensive water quality monitoring. This is particularly important for small water systems, which are the most financial and human resource-strained systems.

The traditional focus for drinking water safety was to rely primarily on water treatment to clean contaminants from water. A good water treatment system provides many guarantees to consumer health. However, it is also expensive, complicated to maintain, and it produces its own by-products (DBPs, sedimentation sludge, etc.). In addition, it can never be 100% reliable, as performance may lower under stressful conditions (Hrudey 2004; Hrudey and Hrudey 2004). Furthermore, according to EPA (2002) the cost of treating contaminated ground water supplies is, on average, 30 to 40 times more (and up to 200 times greater) than preventing their contamination. This makes it particularly difficult for small communities, as the per capita cost for safe water may become too high. In order to provide better and sustainable protection we need to move upstream.

Water safety preventive measures are thus best applied as close to the source as possible, with focus on watershed protection (NZMOH 2002; NHMRC 2004a). Moreover, from a population health perspective, preventing pathogens from even getting into the source water represents upstream primary prevention. This is the most preventive approach that you can possibly have at the present time using reasonable resources. The importance of source protection was also one of the most important recommendations in the Part 2 report of Walkerton Inquiry (O'Connor 2002b). After all, the Walkerton outbreak originated from a polluted water source. If source protection had been assured, the incident would have been less likely to occur even in the absence of effective chlorination downstream.

For a specific water system, this involves identifying the source watershed or recharge zone and possible health risks from contaminants from agriculture, industry, landfills, recreational activities, etc. This step will have to be followed by a risk management plan, developed in co-operation with stakeholders. The risk management plan will have to include measures to limit pollution, an early warning system, and preventive measures and/ or safety barriers to keep contaminants away from the source. In addition, wider interventions may include preparing water budgets to identify surface to groundwater connections and areas of vulnerability, developing emergency plans for water sources, and encouraging agricultural best management practices and local environmental leadership (O'Connor 2002b).

Watershed protection in many cases can be done at very little cost compared to large investments in complex water treatment to remove contaminants from source water that should not have reached the source in the first place. Reduced contamination also reduces water treatment operational costs and generation of treatment by-products. It also represents a much safer approach from the population health point of view. Having less contaminants in the source water is safer than having to remove them continuously, as treatment performance may vary at times.

In the case of small systems, preference should thus be given to choosing the best water source available, and regular sanitary inspections of the water source and of the integrity of the whole system (NZMOH 2001; NHMRC 2004a), rather than to expensive treatment and frequent finished water monitoring.

Moreover, it is unfair and unethical to expect others to clean the water after someone pollutes it. The principle "polluter pays" should be strictly upheld here, as pollution introduces hazards that represent a permanent danger to the health of the population served by the respective system. This danger will then have to be removed over and over again, at high costs and with no certitude that there will not be times when the process will not be as efficient as it should, which presents a constant risk to public health. As pointed out above, wherever feasible, priority should be given to watershed protection rather than to expensive water treatment investments.

4.1.2.2. End-of-pipe verification of drinking water quality should only be used as a final confirmation that drinking water system performance and management is adequate.

End-of-pipe verification of water quality has been the primary focus for assuring drinking water safety. This was viewed as a quick and effective means to assure that the end product is safe. Because of this approach, the focus was placed on meeting the guidelines. As it results from the interviews and questionnaires administered in the study, this became in practice the prevalent approach to assure the safety of drinking water provided by small water systems. While inspections may be carried out in response to positive coliform results in order to assess the state of the system, in practice, systems that are not reported with positive coliform tests are rarely followed up with inspections. Moreover, limitations in staff availability in many public health agencies did not encourage a change to this approach. Due to a widespread belief in the finished water monitoring efficiency to predict unsafe drinking water, this remains the prevalent approach to assure drinking water safety in small systems.

I elaborated in principle 4.1.2.2. on the large limitations of compliance monitoring when used as a sole measure to assure drinking water safety. These have been recognized by water experts for some time and this view is reflected in the new approaches promoted in other countries (NZMOH 2001; IWA 2004; NHMRC 2004a; Hrudey 2005).

The TQM approach to management of drinking water safety was presented above (principle 4.1.2.3.). In this approach, the necessity for finished water monitoring remains, but only as a final check-up to assure that preventive measures in place are effective to contain contamination (NHMRC 2004a; WHO 2004a; Hrudey 2005). In other words, we do not rely on monitoring results to signal deficiencies. The focus is on taking steps to assure that barriers to contamination are in place and are effective, and then we monitor the final product as a last confirmation that we are doing the right thing.

For small water systems, the solution is to adopt a risk management approach as advised in the previous principle and focus efforts on assuring that safety barriers are functional. Treated water monitoring can still be performed, but the priority should stay with preventive measures as above.

4.1.4.3. Targeted, system-specific, monitoring for the most likely contaminants is preferable to non-targeted monitoring for a large set of contaminants.

System-specific water monitoring targeted to detect the most likely contaminants is preferable to non-targeted monitoring for a large set of contaminants, many of which are not likely to be present unless there is system specific evidence to suggest that. In addition, it is preferable to monitor a narrow set of parameters that are indicative of the highest health risks more frequently, than a large set of parameters at large intervals (this applies to both operational and water quality monitoring).

The monitoring requirements should be designed in response to the system-specific, source to tap, risk assessment process, particularly the water quality monitoring. As presented above (principle 4.1.3.1.) the environment presents a myriad of hazards to human health, but only a few can generally be expected to break through the safety barriers of a certain water system with consequences to consumer health. These high risk hazards are to be identified during the risk assessment process. The same hazards should be the main focus of water monitoring.

Ideally, every water system would be able to monitor online finished water for all possibly known contaminants. While contemplating this wonderful fictional scenario, one must not forget that in many cases (particularly for small water systems, but medium size systems can sometimes be included here) they experience a chronic lack of resources that often does not allow them to make necessary improvements. Even weekly sample collection for water monitoring is sometimes a stretch for operator time and their financial resources in small systems.

In an effort to achieve a balance between competing resources, the most sensible approach should be to assure to have at least a reliable monitoring schedule for the high-risk hazards specific to the system. For the same reasons, i.e. optimize the use of time and resources for the greatest benefit in terms of population health protection, it would be preferable to use the results of the risk assessment to establish for each system a short list of likely contaminants (and use indicator contaminants, e.g. coliforms). This short list can then be monitored more frequently, rather than having to monitor at large intervals for a large set of contaminants, most of them unlikely to be present unless notable changes or incidents occur that indicate such risk. (NHMRC 2004a; Hrudey 2005)

Resources wasted on unnecessary monitoring can thus be better invested in more intensive monitoring for high risk contaminants and system improvements.

4.1.4.4. No single drinking water safety barrier is 100% effective against contamination. A drinking water system should have and maintain multiple effective barriers.

In public health we would always, where possible, take several preventive measures at different points in the pathogen transmission cycle. For example, with an airborne infection (e.g. flu) we would not only isolate patients, but also clean surfaces, limit spread by use of proper ventilation, and immunize susceptibles.

The same principle needs to be applied to drinking water safety. We do not want to simply rely on one barrier, no matter how sturdy it may seem. The process of maintaining an effective water safety barrier is complex and still unpredictable. Accidents can happen (e.g. chlorinator failure), changes in source water quality may occur (e.g. high turbidity), and unforeseen or unusual challenges may penetrate a safety barrier (e.g. protozoa). There can be no definite guarantee that a single barrier will never fail (Hrudey 2004).

The last two MMWR Surveillance Summaries (Lee et al. 2002; Blackburn et al. 2004) published by CDC on drinking water related outbreaks report that untreated groundwater remains a primary cause of outbreaks both in the 2001-2002 period (40% of all outbreaks included in the summary) and in the period covered by the previous report, i.e. 1999-2000 (43.6% of all outbreaks). The term "untreated groundwater" indicates a drinking water supply that lacks treatment barriers and relies only on the natural protection believed to be conferred by a confined aquifer.

The book "Safe Drinking Water" (Hrudey and Hrudey 2004) presents many cases where reliance on a single or insufficient barriers resulted in an outbreak when a barrier failed. For example, reliance on chlorination with no or inefficient filtration produced several *Cryptosporidium* outbreaks, including the one in North Battleford, Saskatchewan. It can of course be objected that water operators at that time were not aware of this protozoa as a water contaminant. But the presence of an efficient dual (filtration and disinfection) treatment, coupled with source protection, may have prevented outbreaks even if the existence of *Cryptosporidium* was not acknowledged.

By relying on multiple efficient barriers or redundancies, we assure that should one fail, we can still assure partial protection against potential pathogens in water (NZMOH 2001; O'Connor 2002b; CCME 2004; NHMRC 2004a; WHO 2004a). Since infection is not only a matter of pathogen presence, but also of dose, partial protection may in effect prevent most, if not all, of the population from being delivered a high enough pathogen dose to produce disease, should a treatment failure occur. As it results from the study interviews and questionnaires, some more informed public health professionals already advocate a multiple barrier approach.

The use of multiple barriers is not new for large municipal systems. But many small water systems do not have such safeguards in place yet. Participants in our study often cited costs as a major impediment to achieve this goal, and also that small system operator training, time availability and, sometimes, motivation would make their maintenance difficult. Formal training and support for operators and a focus on source protection, rather than on monitoring, may resolve most of these problems. Small systems need to deliver safe water too, and implementation of multiple safety barriers is a necessary step towards this primary prevention goal.

4.1.4.5. Social, cultural and economic trade-offs of various risk management options should further be considered in decision-making, seeking the greatest good.

After the source-to-tap risk assessment and the development of risk management options, larger social, economic and cultural trade-offs of various risk management options should be considered, seeking the greatest good, provided that protection of public health is paramount. This is consistent with the medical principle of "doing more good than harm". There is no need to require expensive water treatment or extensive monitoring beyond a basic level of safety, if resources can be better used elsewhere with a higher return in population health.

Moreover, it is reasonable to seek investing resources in risk management options that are proportional to the danger posed (Hrudey 2004). Resources are better invested in placing multiple barriers to known population health risks, than in a futile pursuit of absolute zero risk from uncertain health hazards. We already know where the vast majority of health risks lie to drinking water consumers: microbial pathogens (see above). A few chemicals (e.g. arsenic, nitrates/nitrites, lead, fluoride, selenium) can be added to this list where detected in the source at high levels. Thus, preference should be given to measures that prevent such contamination with established waterborne health effects.

On the other hand, drinking water guidelines also include large lists of chemicals, the majority of which have either never been proven to be health risks at environmental levels. If eventually proven for some of them, population health risks at environmental levels are unlikely to be large (see above principle). They may not even be present in the source water above guidelines. Implementing expensive treatment and water monitoring that assures the removal of such substances is unlikely to bring any practical benefits to consumer health. However, the costs for producing water would rise, diverting community and/or private resources from other useful health projects.

The WHO definition of health is: "Health is a state of complete physical, mental and social well-being and not merely the absence of disease or infirmity" (WHO 1948). Thus health means not only absence of disease, but a good quality of life too. In this context, wealth is a major health determinant from a population health perspective (Hrudey 2005). Making people or communities poorer with marginal, if any, benefits to the safety of their drinking water may in fact be contrary to the "doing more good than harm" principle.

Regulatory expectations for drinking water safety should consider such trade-offs, as long as no discernable population health risks are likely based on current evidence.

4.1.4.6. Good communication and risk communication skills are important to achieve consumer confidence, support and compliance.

As noted above, due to its preventive approach, public health practice is inherently an exercise in health risk management. In this context, proper communication of risk is an important tool for public health professionals. Risk communication concepts and techniques should be present in public health training at all levels, as it is essential for both operator compliance with regulations and operational practices, and public compliance with drinking water safety measures. Risk misconceptions should be actively identified and addressed in an understandable manner.

Risk communications aspects related to drinking water safety recognize several components:

First, risks to population health from inadequate or lack of preventive measures and safety barriers have to be explained internally (for large municipal water systems) in order to improve operator understanding, competence and learning capacity.

Second, the same risks have to be communicated to small system operators in an easy to understand manner and linked with practical preventive measures and procedures that prevent health risk to the population. Since enforcement officials (Health or Environment, where applicable) are most often the only contact persons with the operators, they have to continue to act as de facto trainers in this field. Proper risk communication promotes compliance, motivation and responsibility.

Risk communication with the public should assure that consumers and private well owners understand and agree regarding the risks to drinking water safety when present, the need to implement and maintain preventive measures, and the purpose of public health actions. In the absence of proper two-way communication, public health enforcement may be perceived by residents only as rigid, costly and unnecessary (Word 1998). In addition, public health officials need risk management training and expert support to be able to adequately address public and operator concerns on the health risks from biological, chemical and physical drinking water contaminants. They will need to emphasize the importance to prevent microbial contamination and dispel myths on certain chemical hazards (Hrudey 2005). Also, the distinction between aesthetic and public health problems will need to be explained, if tradeoffs are necessary due to local conditions (NHMRC 2004a).

Furthermore, developing and maintaining a two way communication with the community allows to present factual information to consumers and to respond to their concerns. It also allows the identification of specific interests that may be affected and the existing level of understanding on water safety issues. It also promotes community support to drinking water safety initiatives, including preventive measures and watershed protection.

Public education campaigns on safe drinking water practices that are organized by some public health agencies for private well owners represent a typical population health primary prevention intervention, another illustration of the principle "An ounce of prevention is worth a pound of cure". It is better to prevent possible disease in the community, than to have to deal reactively with its consequences. These initiatives may be targeted to other groups, such as high-risk small public drinking water system users.

For example, funding was often referred to as an important objection to improving drinking water safety in small communities. Some interviewees also suggested external financial support to upgrade old and high-risk drinking water systems. In Canada and other affluent countries, the cost of drinking water is generally small compared to many other life necessities, or to non-essential conveniences (Maxwell 2005). Doubling or even tripling the cost in order to provide secure a consistently safe drinking water supply is much more important. Public health professionals will have to change the public misperception that safe drinking water can also be cheap.

Many interviewees and questionnaire respondents acknowledged risk communication as an important part of their role to protect population health, and that proper communication of risk is essential for public confidence in their recommendations.

4.1.5. Regulatory and surveillance aspects

4.1.5.1. Development of non-regulatory risk management options should be considered, while preserving regulations that allow enforcing public health protection.

While regulations that allow regulatory agencies to effectively intervene to enforce public health protection should be maintained, development of non-regulatory risk management options should be considered. Maintaining the capacity to enforce public health legislation is essential, as it provides a strong support for situations when other interventions to benefit drinking water safety do not reach their goal (Saunders et al. 1996b). Participants in our study acknowledged that other agencies resort to contacting the public health agency for enforcement if other approaches are not successful; similar findings were reported in a previous study in Alberta (Wanke et al. 1996). Therefore, this capacity should be maintained as it may provide a last resort for difficult situations involving environmental health risks to population health.

However, non-regulatory risk management options need to be developed that encourage stakeholder co-operation and reduce the need for additional legislation ("enforced self-regulation"). In this context, the development of standard best practices and an operator manual for the management of drinking water for small unregulated systems (Hrudey 2005), combined with organization of operator training and formal support may provide a better alternative to tightening present legislation.

For example, the requirement for a professional risk assessment for every public water system in Ontario (MOE Regulation 170/03), adopted as a reaction to the Walkerton incident, has created high financial burden for small water systems. More recently, it has been proposed to have the assessments done by public health professionals, as a more cost-effective approach (OMOE 2005b).

Along the same line, public health agencies and other regulatory agencies need to develop more alternative intervention strategies (Saunders et al. 1996b) and use enforcement where effective risk management actions cannot be otherwise achieved (e.g. communication and partnership with water suppliers).

The WHO Guidelines for Drinking-water Quality (WHO 2004a) advocate a supportive role and adoption of supportive strategies from agencies responsible for community-managed drinking water supplies rather than enforcement actions, as a more efficient way to achieve population health objectives in the area of drinking water. As it results from the interviews, the implementation of this principle varies across Canada, also influenced by provincial mandate and public health staff time availability. As elaborated in the principle 4.1.1.8., water operators should be respected and supported by the regulatory agency.

4.1.5.2. Formal support for operators (consultancy and information resources) should be organized and funded at provincial or regional level.

As protectors of public health from waterborne pathogens via drinking water, water operators should receive training and continuous support, just like any other public health professionals.

Large municipal water systems generally benefit from experienced and well-trained staff and consultants, including training for public health aspects of water safety. This is not generally the case with smaller systems. At the present time, many of these systems (municipal, communal or private) have to rely on regulatory agency and/or public health staff for guidance. While having also an advisory role it is generally accepted by enforcement officials, this is hardly the best solution by itself. These officials have often diverse responsibilities in many fields related to environment or environmental health, and rarely have the time and training to address all support and educational needs of water system operators in their area. In addition, having the enforcement staff provide professional advice to operators may present a legal problem, as an offender can prevail of such situation in court to his advantage.

Drinking water safety for the whole population would be best served by organizing regional or provincial level water safety specialized resources that are readily accessible to all operators. This can be easily build on the experience of present staff and may resolve the problem of limited water safety specialists that confronts especially public health agencies serving rural regions. I will elaborate more on this in section 4.3.1. ("Assistance needs").

Organisation of regional or provincial units of water safety trained consultants (as in some Australian states and in British Columbia) would better guarantee the quality of drinking water safety support, allow formal dissemination of experience, allow more focused public health training for inspectors and operators, promote legislative and best management practice initiatives, and can also take charge of various water safety activities where a centralized approach may be beneficial (e.g. centralized surveillance of water safety issues). In addition, it can provide written and web resources for professionals. This model has been already successfully implemented in a place with a regulatory environment similar to most Canadian provinces, the state of New South Wales, Australia.

4.1.5.3. Long-term solutions to assure safe drinking water require investigation of various water management solutions.

A long term strategy to drinking water safety should also broaden its perspective and consider strategies that have successfully been implemented in other parts of the world.

In this respect, merely providing tanked water because the municipal water is unsafe to drink is an emergency solution, not a long-term one. Maintaining the status quo consumes resources and is prone to large variations of quality and availability. Yet it does not eliminate the health risk to population because inadvertent consumption of unsafe water may still occur, it maintains a double standard of living for Canadian citizens, and is likely not even cost-effective on long run.

Water regionalization has been successfully implemented several years ago in the Australian state of Victoria. It is also currently considered as a solution for better drinking water management in some Canadian provinces, such as Alberta, and in the U.S. Regionalization can be a key strategy to assure that small water systems reach and maintain the technical, financial and managerial capacity to produce safe water. Water regionalization allows for better use of water resources and may be a solution for reducing per capita costs of producing safe water for rural areas.

Water resource management (WHO 2004a) activities can seriously influence surface water quality downstream as well as groundwater quality. This may introduce risks to drinking water safety and increase water treatment costs. Since preventive measures are more effective and less expensive, preference should be given to water management solutions that consider source water quality.

Watershed management should limit source water pollution in order to protect public health. Public health officials should promote initiatives that protect the watershed and are likely to reduce pollution risks for community source water

Water reuse has been considered in some countries, for example Australia, as a means to reduce the use of high quality water for non-drinking purposes and to reduce nutrients in water bodies (Derry et al. 2003). Australian participants in the interviews have all mentioned the importance of this measure to save water and public health professionals are currently analysing the risk tradeoffs involved and risk communication aspects of this approach. The incentive for water reuse in Australia is their serious and growing water shortage.

Research and development of best management practices to save water are needed, including changes in industry and agriculture practices. Improvements in technology and water management, as illustrated in Gleick (2003) for other affluent countries, may limit the current growth in water use without being accompanied by a loss of prosperity. The experience of other countries may provide useful insights in this area.

4.2. A Framework for Drinking Water Safety

A framework for drinking water safety that reflects all the above key messages should be developed in consultation with all stakeholders. The framework need not replace existing controls. Rather, it should provide a common understanding and the philosophical basis and support for current and future water safety strategies. This framework can be adapted to fit the needs of any specific regulatory jurisdiction. The general elements and components of such a framework are proposed below (Table 17).

Public agencies and other regulatory agencies may encourage the use of this framework by the water industry as a base for a TQM approach to management of drinking water.
The framework may be used by regulatory agencies to develop a provincial drinking water safety strategy. It can also be adapted by public health agencies to propose a regional drinking water safety strategy.

Depending on drinking water regulation in the respective province, this strategy may include all public drinking water systems (if public health is the regulatory agency) or may be adapted to small unregulated systems (when another agency such as environment is regulating municipal systems). In the case of small systems, the framework should be adapted to place a stronger focus on source protection and preventive measures.

Table 17 - Elements of a Framework for Drinking Water Safety

Step	Element	Components	Description
PURPOSE	*Strategy*	Policy	Provincial/Regional drinking water policy statement
		Objectives	Provincial/Regional drinking water safety objectives
RISK ASSESSMENT	*System specific*	Flow chart	Water supply elements and how they connect in the system
		Hazard identification	System-specific hazards, hazardous events, and their causes (at all levels in the system)
		Risk characterization	Based on a semi-quantitative scale
		Prioritisation	Distinguish high risks from low risks
		Risk control	Preventive measures and barriers to contamination in the water system
		Residual risk	Present safety state of the water system
	Regional comparison	Risk level	Provincial/ Regional grading scheme for relative water system safety, based on the result of analysis of previous framework component

RISK MANAGEMENT	*Process*	Operational procedures	Activities necessary to maintain the operation of system safety barriers
		Maintenance	Equipment verification and regular maintenance
		Corrective actions	Actions to be taken in case of deviation from process or product targets
		Contingency plans	Specific protocols to follow in case of unsuccessful corrective actions and/or if hazards may reach customers
		Documentation	Written documentation of all aspects of risk management (log book, etc.)
	Verification	Critical control points	Identify controls who substantially reduce risk, can be monitored, and corrective actions can be applied timely
		Operational monitoring	Monitor process targets (defined based on a system-specific risk assessment and selection of control points) to ensure operational effectiveness
		Drinking water quality monitoring	Monitor product targets (defined based on a system-specific risk assessment and health-based targets) to ensure compliance with guidelines
	Review	Evaluation	Determine performance of water safety plan and improvements
		Audits	(Internal)/ External evaluation of meeting strategic drinking water safety objectives (see above)
		Improvement plan	Decide improvements based on the results of the risk assessment step
		Improvement schedule	Schedule improvements based on a balance between risk priority and available resources

	Reporting	Internal reporting	Internal communication, formalized depending on the size of the system
		External reporting	Reports to regulatory agency, health unit, other stakeholders, consumers, etc. as needed
SUPPORT	*Operators*	Operator awareness and involvement	Develop communication procedures to involve in relevant decisions and motivate operators
		Operator training	Assure that operators have enough knowledge and skills to operate the system and meet framework objectives
	Research	Validation	Validate drinking water processes and technologies
		Development	Investigate improvements, new processes and technologies, emerging water safety hazards
	Consumers	Communication	Encourage two-way communication with consumers to promote awareness of water safety issues
		Community involvement	Develop a culture of community involvement in decisions about drinking water safety
	Resources	Internal Consultants	Provincial or regional drinking water safety resource people
		Information materials	Library, web, brochure development, etc.

4.3. Assistance and Training

Drinking water safety assistance and training needs of public health professionals have been identified based on a gap analysis of current discrepancies between the current knowledge, role and practices and the drinking water safety population health framework and key principles presented before. Assistance and training recommendations for public health professionals are summarized in Table 18. I included in Appendix G a generic orientation document that can used or adapted to assist RHA health boards in assuring that the public health agency is discharging their responsibilities to drinking water safety in their region.

Table 18 - Recommendations for assistance and training

Assistance
1. Development and adoption of a regional or provincial drinking water safety strategy based on population health objectives
2. Identification of alternative, non-regulatory, risk management options
3. Drinking water safety surveillance
4. Regional/ provincial water safety resource centres
5. Clarify jurisdiction to assure complete coverage of drinking water issues
6. Regulatory and non-regulatory promotion of long-term solutions to safe drinking water
Training
Public Health Inspectors
1. Role and responsibilities for drinking water safety
2. Environmental hazards in drinking water
3. Drinking water systems
4. Environmental health risk management
5. Risk management for safe drinking water
6. Communication, public relations and risk communication
7. Training and education skills
Water Operators
1. Environmental hazards in drinking water
2. Drinking water systems
3. Risk management principles for drinking water systems
Medical Health Officers
1. Waterborne diseases
2. Waterborne outbreaks
3. Risk management principles for environmental contaminants in drinking water
4. Risk management principles for drinking water systems
5. Drinking water safety strategy

4.3.1. Assistance needs

In order to implement the drinking water safety principles presented above, this section lists the priorities for assistance other than training.

4.3.1.1. Development and adoption of a regional or provincial drinking water safety strategy based on population health objectives

Whether or not provincial legislation places the public health agency in an explicit leading position, safe drinking water is primarily a population health measure. Therefore, public health agencies should assure that a provincial or regional strategy based on the same population health principles that are applied in any other public health area is adopted for drinking water safety. This strategy will have to be developed in co-operation with regulatory agencies for drinking water, environment and water resources, as well as any other relevant stakeholders, depending on jurisdiction. While large municipal systems expertise may be involved, small water systems should be the primary target for improvement since they are the most vulnerable.

As detailed before, developing population health targets based on health status objectives is not viable for most Canadian regions, since the population health impact of any strategies are likely to be undetectable over the short term. The benefits will come from making waterborne outbreaks less likely, but this benefit will not be measurable over periods less than decades. Instead, risk assessment based intermediate targets should be commonly employed for drinking water safety strategies. I have provided examples of intermediate targets in the "Key principles" section.

4.3.1.2. Identification of alternative, non-regulatory, risk management options

Some participants recommended the adoption and implementation of stricter safe water legislation. Certainly, a strong enforcement capability should be assured and maintained for worst case situations. In particular, watershed and source protection should be enforceable when needed as a public health measure.

However, drinking water safety strategies are more effective if they focus on identifying and promoting alternative, non-regulatory, approaches that promote co-operation, partnerships and transparency among stakeholders. They should support best practices standards for a quality management approach to drinking water, based on the key principles presented previously. Development of these standards should be based on risk management principles applied from source to tap. Best practices standards should be adaptable to system capabilities, with practical solutions for small water systems (e.g. promotion of source protection and other preventive measures).

Even more than in other public health areas, safe drinking water is the result of good team work, co-operation and collaboration with all stakeholders (unless the public health agency is entirely responsible for all drinking water provision aspects, from watershed to consumer). Team work and mutual trust is nurtured by co-operation, rather than by enforcement. The best way is to achieve a partnership between the public health unit, regulatory agencies, water system operators and public representatives, rather than a power relationship. On the other hand, the public health agency has to remain faithful to its mission as guardian of health for the community they serve. Therefore, they will still have to step in and enforce public health protection if they have exhausted other alternatives and have unresolved concerns. What this means in practice may vary, since it is difficult to suggest a "one size fits all" solution. However, if public health is not adequately protected by other stakeholders, then the public health agency will have to initiate the corrective process.

4.3.1.3. Drinking water safety surveillance

The value of drinking water safety surveillance based solely on the laboratory analysis of water monitoring is very limited (in terms of PPV and NPV) for public health protection. It resembles the value of a public health infectious disease surveillance system based solely on headache. That is, a headache may or may not be present in case of infection, it does not specifically relate to the presence of any particular pathogen, and may be present in many other non-infectious conditions that could be medically relevant or not. This would make it a very poor case definition for most infectious disease surveillance purposes.

The same goes for a drinking water safety monitoring based solely on positive coliform testing. As elaborated in section 4.1.2.2., water monitoring for pathogens has low PPV, low NPV, is little representative for the water volume and does not consider viability and infectivity. These considerations apply also to coliform monitoring that is used as an indicator of potential fecal pathogens. The value of water monitoring as the sole predictor for consumer health risks is thus generally limited for raw water and very limited for treated and distribution water (where the low prevalence of contaminants further lowers the PPV). We need better water quality monitoring approaches coupled with a good understanding of the specific drinking water system to make such data more meaningful.

A drinking water safety surveillance system should be based on an inventory of all drinking water systems. Each water system must be subjected to a system-specific risk assessment and risk grading (to assist in prioritising improvements and further system surveillance). Every water system will then have to develop a system–specific risk management plan. Periodic inspections will verify compliance with the risk management plan provisions, in particular based on operational monitoring using indicators of barrier efficiency in critical control points (e.g. chlorine residual to check disinfection). Surveillance would be based on raw and treated water monitoring, and on barrier failures and near failures.

4.3.1.4. Regional/ provincial water safety resource centres

Development of regional or provincial water safety resource centres should be considered to support the implementation of the drinking water safety strategy. While dedicated water safety consultants are necessary in most regions, it is often not possible to afford them due to limited funding. Pooling resources together in provincial or regional resource centres covering several RHAs is likely to reduce costs and redundancies and assure specialist support is available to public health professionals when needed.

The centre could be designed in several ways depending on how its mandate is defined. For example, as noted in the previous section (4.3.1.3.) an essential step in the drinking water safety strategy will be to create an inventory of all drinking water systems in each RHA, which will then all be subjected to a risk assessment and risk grading process. The centre may then maintain a centralized and comprehensive water safety surveillance system that could include an inventory of water supplies with system description, results of risk assessment and risk grading system inspection, as well as the microbiological and chemical monitoring schedule and results for each system. This surveillance system would allow centralized access to information and reduce the reporting burden at the public health agency level. Ultimately, such a resource could be used to follow implementation and compliance with risk management plans by every water system, with water quality monitoring results data being used as the confirmatory rather than the sole check-up measure.

By the use of historical data, the centre may assist in reporting trends and identifying high-risk areas and common risk factors to inform targeted drinking water safety interventions (education, funding, system improvements). In addition, a reporting system to record system failure and near failure events should be developed to assist future learning from local experience. While small public drinking water systems should be the main focus, depending on needs surveillance can include large or private systems as well. Access to the inventory can be available to stakeholders (e.g. water operators, laboratories, public health staff) over a secure Internet connection.

The resource centre can build their internal capacity by using local expertise, while external consultants (e.g. university) may be involved when there is need for more specific expertise. By using available information resources and staff expertise, the resource center can then assist public health officials with specialist advice, organize needs-based drinking water safety training for public health professionals, as well as organize formal training and/or provide assistance in problem solving to water operators (either for all, or only for small systems, depending on local needs and available expertise).

In addition, many study participants have remarked that the staff and resources in their agency are too stretched at present to even consider a proactive role in drinking water safety. By centralizing some of the administrative aspects of drinking water safety, the resource centres can help public health professionals to have more time for prevention activities.

4.3.1.5. Clarify jurisdiction to assure complete coverage of drinking water issues

It will be the role of every provincial government to assure a clear delineation of jurisdiction and responsibilities in the area of drinking water safety between the different parties. Establishing the necessary legal and institutional arrangements to assign appropriate responsibilities among various institutions can be approached in several ways. One option would be the adoption of a safe drinking water act that brings together various pieces of legislation pertaining to drinking water. Another option may be to adopt a provincial drinking water safety strategy and adjust various regulations to clarify the roles of each agency. The purpose will be to assure complete coverage of drinking water issues in order to avoid "grey" areas that may leave public drinking water systems without proper surveillance and to facilitate effective resolution of issues that may affect drinking water safety in the watershed to consumer chain. The different institutions will have to work in partnership both at the provincial and local level to protect drinking water safety.

4.3.1.6. Regulatory and non-regulatory promotion of long-term solutions to safe drinking water

Since safe drinking water is a major population health determinant, assuring sustainable safe drinking water supplies for all communities represents an important component of any drinking water safety strategy and a major responsibility for every provincial government. Sustainable safe drinking water supplies would be water supplies that can be sustained indefinitely in terms of both quantity and quality, taking into account the needs of present and future users. Identification of best water sources for the community supply, watershed protection, and the promotion of water regionalization, water reuse and judicious water resource management are all measures that must be considered to achieve this goal. A primary target should be remote communities that are chronically under boil water advisories, in some instances for years (over six years in one case related by an interviewee). While the extent of problems may vary, every province seems to be confronted with problem situations in small supplies.

Different stakeholders should be encouraged to co-operate to identify the best option that assures each community with a safe and sustainable drinking water source. Drinking water safety consultants may assist with system risk assessment to identify solutions and prioritise improvements. Education and incentives need to be targeted to stimulate communities to take responsibility for their drinking water supply. For example, funding was often referred to as an important limitation to improving drinking water safety in small communities. Subsidies can be provided in exceptional circumstances to impoverished communities to secure a safe drinking water supply, but in general it is preferable to encourage consumers to support the real cost of safe drinking water. Externalizing costs for producing safe drinking water is unlikely to be a sustainable solution.

A water safety centre may also promote collaboration with other institutions with a stake in water resource management to develop solutions that secure sustainable supplies of drinking water in the context of future population growth and industrial, agricultural and community development.

4.3.2. Training needs

Several training needs have been identified for different groups of public health professionals: MOHs, PHIs, and water operators. They are presented below separately for each group, organized on several training themes. The gap analysis was based on comparing the current knowledge and understanding that most professionals have based on the results of the study to the requirements for a complete population health approach to drinking water safety. Safe drinking water is the result of a team effort and public health professionals have to be competent and well-informed members of that team.

Training recommendations are not aimed to replace the current knowledge of public health professionals; rather it is targeted to build on their experience and training to improve their impact on improving drinking water safety in their region. Future training must consider each of the key principles for a population health approach to drinking water safety introduced in the previous section. In particular it should emphasize a total quality management approach to drinking water safety based on risk management principles, rather than relying on water monitoring as the primary drinking water safety management measure.

4.3.2.1. Public Health Inspectors / Environmental Health Officers

From a public health perspective, PHIs/EHOs as a professional category are the most involved with drinking water safety. They represent the field staff that has to inspect facilities and enforce drinking water safety. They are often in contact with other stakeholders and co-operate to assure safe drinking water. They also provide advice on public health issues related to drinking water to water system operators and other agencies. In order to prepare them to promote a population health approach to drinking water, they would need training on the following topics.

Training topics

Role and responsibilities for drinking water safety

In provinces/states with a safe water act, training should be primarily focused on developing an understanding of the letter as well as the spirit of the law. In provinces without specific safe water legislation, training should emphasize that public health professionals need to be faithful to their mandate to the public and stay constantly involved in all aspects that impact water safety, while at the same time working together with water engineers and operators to ensure public health objectives are met. This should not only include following up on adverse water monitoring results, but a comprehensive risk management approach to drinking water safety. It should involve also participation in all relevant decision-making bodies that impact water safety, including watershed management groups. This module could be an introduction to the concepts that will be expended in the next modules.

Environmental hazards in drinking water

The focus should be on common as well as emerging pathogens, like protozoa and viruses. Chemical hazards of local significance should be included, but in general it will have to be emphasized that microbial contaminants represent known health risks with sometimes severe consequences, whereas, unless massive contamination occurs with acute effects, for most chemicals the chronic health risk is still theoretical (arsenic and lead would be some exceptions).

PHIs would need to learn about all classes of microbial pathogens and characteristics of each class (bacteria, protozoa, viruses). Pathogens relevant to waterborne disease will have to be described individually. Each pathogen should be introduced regarding general contribution to waterborne illness, characteristics, strains, infectious dose, viability and infectivity aspects, modes of transmission, environmental sources, survival in the environment, resistance to water treatment, type of disease produced and symptoms, laboratory detection, and susceptible populations. In addition, details of best water treatment approaches would be very helpful since inspectors may need to advise local water operators.

As noted above, various classes of chemical environmental hazards (inorganic and organic) and natural toxins (e.g. algotoxins) can be presented with description, natural/artificial sources of contamination, their relevance to human health (acute and/or chronic health concerns, symptoms of acute intoxication where relevant), and water treatment removal.

A section on waterborne outbreaks can be included here or organized as a separate module. The training should include definition and characteristics of waterborne outbreaks, common causes and patterns, specific detection and investigation against background level of enterics in the community, and case studies based on previous outbreaks. Sometimes, outbreak investigation is the responsibility of a separate infectious disease team within the public health unit. In this case, the module can focus on training these professionals, or both groups (i.e. environmental health and infectious diseases). General outbreak investigation training may be considered as a prerequisite for this section.

Recommended bibliography: Hunter 1997; AWWA 1999; Yassi et al. 2001; Lee et al. 2002; Blackburn et al. 2004; Cloete et al. 2004; Hrudey and Hrudey 2004; WHO 2004a; Meinhardt 2005; Moeller 2005

Drinking water systems

Since PHIs are the *de facto* trainers for many small system or private operators (either by law or by default), they should be the first to receive drinking water treatment training, including the design, operation and maintenance of a small drinking water system. This is public health training. Many respondents and interviewees regarded this as an important area of knowledge for all PHIs that have to oversee rural areas. It was also often mentioned as a training need, indicating they feel that are not always up to the challenge. Of course, this should be integrated in a risk management approach to drinking water safety.

Training should include drinking water hazards, hazardous events and causes, for example source pollution, treatment failures, distribution backflow, cross-connections with sewage or non-potable water, and other issues. This should be followed by a presentation of safety barriers to drinking water contamination along the watershed to consumer continuum, that includes the description and purpose of elements of a water system, and capabilities of various water treatment processes (advantages and limitations) and preventive measures (e.g. source protection). Participants will also have to learn elements of waste water management.

While not required to operate a drinking water system themselves, PHIs will have to understand the principles and best practices of water system operation and maintenance, as well as principles of operational control, including critical control points, operational monitoring, operational limits, and what actions to take to correct exceedance. In particular, PHIs need to know the purpose of barriers and of significance of operational indicators used to monitor water system operation. For example, during the outbreak in North Battleford, public health inspectors (as well as professionals responsible for water treatment) were unable to connect the lack of floc formation (which is essential for effective filtration) with the possibility of *Cryptosporidium* oocysts contamination reaching drinking water delivered to population, even as the outbreak was unfolding (Hrudey and Hrudey 2004).

Another important training topic will have to be verification of drinking water quality by monitoring microbial and chemical indicators, monitoring consumer satisfaction (surveys, taste and odour complaints), and understanding the significance of various indicators (e.g. total vs. fecal coliforms). In addition, they need training in data interpretation for effective decision-making.

Experienced PHIs may be more confident in the interpretation and decision-making based on common water monitoring results and their experience often make them intuitively aware of the possibility of false positive or false negative results. However, in general these professionals need a better understanding of the limitations of water monitoring. When the full chain from sample collection through analysis and interpretation is considered, false results are inevitable.

PHIs would first need training to get a critical understanding of how lab results are generated. In addition, most questionnaire respondents expressed an incredible belief in the significance of a positive lab results to indicate the true presence of a rare pathogen, some even to the extent of refusal to question such result as being a false positive. PHIs need to understand that a positive lab result does not equal true presence of a hazard, and this difference is becoming larger as the hazard is less frequent, to the extent that single results for rare hazards are practically unreliable without validation (Hrudey and Leiss 2003; Hrudey and Rizak 2004). In addition, another misconception is that a negative monitoring result invalidates a previous positive finding. This ignores the fact that water monitoring is normally a hit-and-miss process (Allen et al. 2000).

While the possibility and the public health impact of false negative results seem to be better understood, they need to understand that even gold-plated laboratories may produce false positive results when monitoring treated drinking water and that false positive results have negative consequences too. Another Sydney crisis (see Hrudey and Hrudey 2004) with financial and credibility loss consequences is not desirable for any municipality. Some more informed respondents emphasised that the suspected pathogens may be present, but not viable or truly the pathogenic strain. While the lab may or may not have the capacity to distinguish between those variants for every pathogen, the lab diagnostic method will experience excess false positives when screening for hazards. Thus, another training topic should be the critical understanding of the relevance of lab results in the context of sampled medium (e.g. raw vs. finished water) and their use in risk management decision-making.

Learning can be assisted by using case studies on waterborne outbreaks emphasizing system and monitoring limitations, lack of sufficient barriers, and barrier failure patterns.

Recommended bibliography: NZMOH 2001; Hrudey and Leiss 2003; CCME 2004; Hrudey and Hrudey 2004; Hrudey and Rizak 2004; NHMRC 2004a; WHO 2004a; NHMRC 2004b

Environmental health risk management

As presented before, assuring drinking water safety is essentially an exercise in health risk management (Hrudey 2004). Therefore, PHIs need a solid understanding of the concepts of health, risk and safety, of the concepts of uncertainty and variability in risk analysis, and of risk tradeoffs in a population health approach to drinking water safety, including the precautionary principle. For example, judicious decision-making involves balancing tradeoffs of major public health decision/action (e.g. call a BWA). Frequent false alarms can have the consequence of reducing public trust in their competence and reduce compliance with public health advisories and other actions.

Moreover, receiving health risk assessment training would improve their understanding and decision-making in regards to environmental health issues they face in drinking water safety, like natural arsenic in groundwater supplies, lead from municipal systems plumbing, nitrates/nitrites from agricultural practices, and similar issues. They therefore need to understand the basic principles and the steps of the risk assessment process for chemical environmental contaminants:

issue identification; hazard identification (assessing toxicological and epidemiological evidence); dose-response; exposure assessment; and risk characterization. As well, they may receive an introduction to the challenges and present models proposed for microbial pathogen risk assessment.

Furthermore, they should understand essential environmental health risk management principles, using practical examples that are relevant to drinking water safety.

Recommended bibliography: Thomas and Hrudey 1997; enHealth_Council 2002

Risk management for safe drinking water

An understanding of the risk management process for drinking water systems is essential to have the correct perspective on drinking water issues they are confronted with. PHIs will have to understand the source to tap approach to drinking water safety and the purpose of multiple barriers (conceptual and how it applies in practice). Training should emphasize source protection versus costly water treatment alternatives as a risk management solution particularly for small water systems. The rationale and advantages of this approach have been presented in the previous section.

They would also have to learn the process of a system-specific assessment, including system analysis, assessment of water quality data, hazard identification, risk assessment and risk characterization, and risk grading. Based on this training as well as the previous module, they will learn to develop a risk management plan for a drinking water system. This should include also incident management (contingency and emergency planning, documentation, and communication) and water system improvement principles (residual risk, planning improvements, setting improvement priority and schedule) for small water systems. Last but not least, they should understand water system inspection and how to audit the risk management plan.

Recommended bibliography: O'Connor 2002b; CCME 2004; Hrudey and Hrudey 2004; Nadebaum et al. 2004; NHMRC 2004a; WHO 2004a

Communication, public relations and risk communication

Public health agencies are always involved in addressing public concerns on the safety of their drinking water. While citizens may also choose to contact directly their water provider, or sometimes the regulatory agency (which most often is the local office of the environment body), in the public's eyes the public health agency is often highly regarded as the most competent and reliable source of unbiased information for their water safety concerns.

PHIs should not only have an understanding of the most routine aspects of drinking water safety (which is expected to be the case), but also be able to deal with unusual circumstances and concerns in a timely manner. At a minimum, they should be able to assess what certainties and uncertainties exist about the respective issue, be confident about what can and what cannot be affirmed about that issue, and provide options or a solution in a timely manner. This may, of course, involve consultation with various specialists, and management would be well advised to create and make available a short list of such people in case their staff may not have their own direct contacts.

Risk communication skills to address concerns of various audiences are very important, since public perceptions determine their overall performance and also because public opinions are in practice one of the most influential factors to the way drinking water safety is eventually managed. PHIs need to be able to effectively convey their message to the lay public in an understandable manner, acknowledging their position and concerns, and use their local knowledge.

Many respondents and interviewees have remarked that public perception is likely the most difficult barrier towards promoting safe water programs/ project/ initiatives. For example, many private and small system owners would object to assuring effective safety barriers in their system because of their unwarranted belief in the security of their water source, or would only do the minimum required for compliance (e.g. shock chlorinate before water sample collection). Even when presented with positive bacterial results from samples from their system they would deny the significance and the need for treatment based on arguments of never getting sick, that occasional diarrhoea is not an important concern, fear of chlorination by-products and similar objections.

Sometimes, the contribution of drinking water to the background level of fecal-oral enteric infectious disease incidence in a community can only be unveiled by the reduction in the incidence that results from upgrading water treatment (Pruss et al. 2002; Goh et al. 2005). Such arguments also obviously ignore that the town of Walkerton used a well vulnerable to contamination for 22 years (O'Connor 2002a) as one of the sources for their drinking water before all conditions lined-up to produce a full and severe outbreak (rain runoff carrying heavy manure contamination containing *E.coli* O157:H7 along with other pathogens into the well, well not taken temporarily out of service in spite of ineffective chlorination). Given the well vulnerability and inadequate chlorination practices, it is quite likely that Walkerton residents too have been exposed to low-level intermittent bacterial contamination in drinking water all these years preceding the outbreak, which may have produced occasional diarrhoea in a few residents but not enough to produce a visible epidemic. Minimising the mismatch of perceptions between public health, lay public, and other stakeholders is at least as important as using good science.

General communication and public relations training is always needed for public health professionals given the nature of their job which is going out to work with the public, businesses and other professionals (e.g. engineers, water operators). In some way, any inspector who managed to stay in their position for more than a couple of years is probably already quite good at this. Nevertheless, some questionnaire respondents did express an interest to receive training in this field.

In order to be able to inform and educate the public about risk these professionals need specific and targeted risk communication skills training, backed by a solid understanding of risk assessment and risk management principles as above . For example, many stakeholders may hold misperceptions about health risks from microbial pathogens versus chlorination and other disinfection processes. While research on disinfection by-products continues, good risk communication would assist stakeholders to understand that microbial pathogens present clear and certain health risks in order to make informed judgements about priorities for safe drinking water.

Several respondents and interviewees have explicitly or implicitly indicated that they strongly feel a need to get more training in these areas. This is one conclusion of the study; unfortunately these topics were not explicit options in the questionnaire, nor were they specifically included in the interview. They were only revealed during data analysis.

Recommended bibliography: Word 1998; Slovic 2000

Training and education skills

In most, if not all regions visited, it seems that PHIs are the main source of advice on water safety matters for small system owners, regulated or not. Therefore, training them to assist the operators with more advanced expertise and information would eventually enhance operator training. It would also empower PHIs to better deal with the variety of issues they may encounter. In addition to the topics presented before, training and communication skills are needed for their relation with operators, in order to ensure that the information above, particularly maintaining water safety barriers and developing risk management plans, will be efficiently transmitted to water operators they are currently educating.

Environmental Health students (future PHIs)

In the future curriculum, more emphasis will be needed in the areas of public relations, risk communication (how to explain the need for water treatment and transmit a correct perspective on the health risk of chemical contaminants), and small water systems operation (include site visits to get familiar with all aspects of the water treatment and distribution, and/or to practice risk assessment principles). These topics are particularly important for students who will then get positions in rural areas.

Training delivery

Professionals in some regions felt that they should have better funding to improve access to training, whereas others estimated that their training budget is sufficient. A regional/provincial water safety resource centre as presented in the "Assistance" section would likely reduce training costs in terms of travel and accommodation, and may also organize local training with minimal administrative costs.

For current PHIs, the main focus should be on modular courses on defined topics: e.g. source protection, water system risk assessment, development of a risk management plan, water quality monitoring. In addition, local workshops may address more specific issues (e.g. arsenic contamination, groundwater source assessment). The duration of training events should not normally exceed a couple of days, due to limited time availability. Several interviewees recommended also inviting water operators in the same events, since it would allow for issues to be discussed openly and would improve their acceptance among them.

Online courses or information resources may be developed by water safety resource centres in collaboration with professional bodies, like the Canadian Institute of Public Health Inspectors (CIPHI) provincial branches, to supplement direct training events. As noted in interview summaries, online courses alone may have limited efficiency and even outreach, as in some areas they may be limited by the lack of computer infrastructure.

Provincial public health representatives in co-operation with the CIPHI branch may define a provincial standard of minimal knowledge and training in water safety for its members. The professional body may also consider co-operating with universities to develop a postgraduate certificate program in water safety, to provide more structured and advanced training to inspectors preparing to become drinking water consultants.

4.3.2.2. Water operators

Water operators play a crucial role in assuring safe drinking water. No drinking water safety strategy is likely to succeed without training water operators as competent drinking water public health professionals. As the history of waterborne outbreaks show, mistakes can make thousands of people ill and some may even die. Operating a public drinking water system represents a major public health responsibility. Recognition of water operators as public health professionals is necessary in order to receive adequate training. A truly preventive strategy for drinking water safety requires the implementation of a training and certification system for all operators of public water systems, regulated or non-regulated. If we license every wastewater operator, why should we not license every drinking water operator?

Producing safe drinking water is not a simple mechanical operation. It is a public health responsibility that requires every operator to understand the reasons for which the source needs protection and water has to be treated and disinfected, the risks that have to be reduced/eliminated, the consequences of failure, the challenges to do this constantly without failure, and their own responsibility to consumer health.

Operators for regulated drinking water systems receive formal training and are certified on water system operation of various complexities. Such programs may be extended and adapted to non-regulated public drinking water system operators. Such an initiative is presently developed in British Columbia. Furthermore, all water operators have to receive basic population health training in addition to their technical training in order to understand their public health role and to appreciate the importance of their work. They need not only to know how to operate and maintain their system mechanically, but to understand the purpose of water treatment, know their system and its capabilities, be able to evaluate risks, understand the role of present barriers and preventive measures in protecting consumer health, and be able to manage the risks under both normal and challenging conditions. They would also have to learn problem solving in a risk management approach to drinking water.

Training topics

Environmental hazards in drinking water

Water operators should be introduced to microbial pathogens and characteristics of each class (bacteria, protozoa, viruses). They will have to learn individual pathogen properties relevant to drinking water safety for common and emerging pathogens. Training will have to introduce aspects similar to PHI training; however, it has to be adapted for their level of education. Each pathogen should be described by its general contribution to waterborne illness, characteristics, modes of transmission, environmental sources, survival in the environment, resistance to water treatment, type of disease produced, laboratory detection, infectious dose, viability and infectivity aspects, and susceptible populations.

Similarly, chemical environmental hazards (inorganic and organic) and natural toxins (e.g. algotoxins) will have to be introduced and their properties relevant to drinking water safety discussed. Training may address natural/artificial sources of contamination, relevance to human health (acute and/or chronic health concerns, symptoms of acute intoxication where relevant), and water treatment removal principles.

Training should transmit the correct order of priorities from population health perspective, emphasising the importance of microbial pathogen control as the primary focus of their activity.

Recommended bibliography: Raucher 1996; Yassi et al. 2001; Hrudey and Hrudey 2004; Moeller 2005

Drinking water systems

Drinking water legislation and some of the following elements are part of operator training for regulated systems at different levels. Nevertheless, water operators need to learn about hazards and hazardous events that may affect water quality, possible causes (e.g. source pollution, treatment failures, distribution backflow, cross-connections with sewage or non-potable water, and other issues) and barriers to drinking water contamination.

Both regulated and non-regulated systems' operators will have to be trained about water system elements, water treatment technologies (coagulation, filtration, disinfection, and new technologies), and preventive measures (e.g. source protection). For small system operators, the importance of source and watershed protection will have to be emphasized as an effective and cost saving preventive measure. Furthermore, they need to learn water system operation, maintenance, and documentation, as well as operational control principles (i.e. critical control points, operational limits, operational monitoring, and corrective actions). For example, they will have to understand the purpose of common operational parameters such as turbidity and the chlorine residual, the importance of maintaining them within operational limits, and the public health consequences of failing to do so.

In order to improve their understanding of water monitoring results, they will also need to know the purpose and limitations of microbial and chemical monitoring indicators used to verify water quality, consumer satisfaction, significance of indicators, data interpretation.
Training may also consider presentations of case studies on waterborne outbreaks to emphasize the importance of principles presented. A drinking water safety surveillance system may also contribute to these case studies by providing examples of failures and near failure and analyze them to improve knowledge and understanding of issues.

Recommended bibliography: NZMOH 2001; O'Connor 2002a; O'Connor 2002b; MWC 2003a; CCME 2004; Hrudey and Hrudey 2004; NHMRC 2004a

Risk management principles for drinking water systems

Water operators also need an understanding of major risk management principles for drinking water. The have to be introduced to the source to tap approach to drinking water safety and the concept and purpose of multiple barriers.

To improve their understanding of challenges as well as their management of the system, they have to be able to perform a system-specific assessment including system flow-chart, identification of hazards at various points in the system, as well as risk assessment and risk characterization for these hazards. Ultimately, they have to be able to develop and implement a risk management plan for their system with focus on preventive measures and effective operational monitoring of barriers. The plan will also have to include incident management provisions, such as contingency and emergency planning. Moreover, they will have to be able to develop a water system improvement plan based on residual risk, planning improvements to address high risks first.

Recommended bibliography: NZMOH 2001; O'Connor 2002b; MWC 2003b; CCME 2004; Hrudey and Hrudey 2004; NHMRC 2004a; WHO 2004a

Training delivery

Public health and health risk management training can be integrated into regular training for operator of regulated systems. Alternatively, training can be organized by a regional water safety resource centre in co-operation with the regulatory agency.

Training for water operators of non-regulated systems will have to include a system of formal training and certification as public health professionals. Training can be organized by local water consultants or a water safety resource centre into local courses. Training may involve the public health agency and experienced water treatment professionals from municipal systems or regulatory agencies. Development of a user manual for small water systems may also complement their training.

4.3.2.3. Medical Officers of Health

Medical officers have to cover many responsibilities beyond drinking water safety. In general, they are not routinely involved directly in drinking water safety surveillance, since they are delegating this activity to their environmental health team. However, assuring drinking water safety in their region is part of the medical officer's mandate as protector of population health. They supervise the public health activity in their region and represent the public health agency at the RHA management level. Also, they often represent the public health voice to the public and media. Therefore, medical officers are involved in all high-level decisions and major public health actions regarding drinking water safety (e.g. public health advisories).

In addition, medical officers of health are sometimes required to provide an official opinion on behalf of the public health agency regarding population health impacts of a drinking water safety issue. They have to provide public health guidance and medical opinion on the health risk from environmental contaminants, both internally, to their staff, and externally, to other agencies or the general public. They also have to provide advice to local physicians and other health practitioners in their region on the diagnostic, treatment and prevention of diseases of environmental aetiology.

The following represents a recommended curriculum for future medical officer training in management of drinking water safety. Some topics are similar to the PHI curriculum; however, for these topics the focus will have to be less on treatment technologies and more focused on their significance to population health and future public health strategies for drinking water safety.

Training topics

Waterborne diseases

MOHs would need refreshers and updates on emerging waterborne microbial pathogens. Updates may include a presentation of trends in infectious diseases that may recognize water-related transmission as well as specific waterborne infection data based on indigenous and international statistics (from other affluent countries). Emerging pathogens should be introduced individually with relevance to drinking water safety, characteristics, infectivity, sources of contamination, mode of transmission and environmental survival. This should be followed by evaluation and management of pathogen exposure, including specific disease pathology, clinical presentation (signs and symptoms), laboratory tests, treatment principles, and the risk to susceptible populations (often immunocompromised of various cases, but also higher exposure or higher susceptibility groups). Principles of prevention, water treatment removal capability and pathogen resistance (e.g. barrier efficiency in respect to each pathogen) will have to be emphasized for every pathogen.

In addition to microbial pathogens, relevant classes of chemical environmental hazards (inorganic and organic) and natural toxins (e.g. algotoxins) can be presented with description, natural/artificial sources of contamination, (acute and/or chronic health concerns, symptoms of acute intoxication where relevant), and water treatment removal. Their relevance to human health will have to include evaluation and management of exposure to most important chemical hazards: pathology; clinical presentation of disease (signs and symptoms); laboratory tests; treatment principles; and the risk to susceptible populations (more common being high-exposure or high susceptibility groups such as children, elderly, pregnant women).

This session will have to be concluded with recommendations for public health advisories (e.g. boil or 'do not drink' water) and risk reduction guidelines for susceptible populations.

Recommended references: Hunter 1997; AWWA 1999; Lee et al. 2002; Blackburn et al. 2004; Hrudey and Hrudey 2004; Meinhardt 2005

Waterborne outbreaks

This part will follow on the waterborne disease module and must include trends in waterborne outbreaks in affluent countries and case studies on the waterborne outbreaks of both common and emerging pathogens, emphasizing contamination source and causes of the incident, critical water system flaws, critical prevention measures that were not implemented including upstream prevention (e.g. watershed protection), barrier failure and causes, common incident and detection patterns in these outbreaks and recommended practices to prevent their occurrence. Ample time should be allowed for analysis and group discussions.

Recommended references: Hunter 1997; AWWA 1999; Lee et al. 2002; Blackburn et al. 2004; Hrudey and Hrudey 2004

Risk management principles for environmental contaminants in drinking water

In relation to the health risk that a water contaminant poses to the public, particularly for less common contaminants (e.g. algal toxins, hydrocarbons), participants in the study noted that public health professionals recognize increasing sources of contamination and types of contaminants as well as many challenges in providing expertise and support to public and other stakeholders.

The module will introduce environmental health risk management concepts, such as risk, uncertainty and variability, and safety. Risk management principles and risk tradeoffs will have to be introduced within a population health approach to drinking water. This should include the significance and practical applications of the precautionary principle.

Principles and steps of health risk assessment will have to be presented with application to common chemical environmental hazards (including algal toxins) and including approaches to risk assessment for multiple contaminant exposure (e.g. hydrocarbons). This can be followed by case studies on arsenic, nitrates, lead, or other local issues of concern.

In addition, participants will need to learn applications of the risk assessment principles to microbial pathogens, common approaches and challenges of microbial risk assessment models, applications of risk assessment and epidemiology research to answer drinking water risk management questions regarding pathogen exposure (e.g. identification of high-risk systems).

Risk communication principles will have to be introduced with application to environmental health contaminants in drinking water.

Recommended references: Thomas and Hrudey 1997; Slovic 2000; Simmons et al. 2001; enHealth_Council 2002; Ashbolt 2004; Martuzzi and Bertollini 2005

Risk management principles for drinking water systems

The module should first introduce risk management principles relevant to drinking water safety. The focus should be on risk reduction and prevention of waterborne illness in a source to tap approach to drinking water safety.

The training will present water system elements and their purpose, presenting possible hazards, hazardous events and their causes at every point in a drinking water system. The purpose, capability and limitations of drinking water safety barriers will have to be presented, as well as principles of operational monitoring and control, with emphasis on the significance of common surrogates and indicators to health risk. This should include the multiple barrier concept and applications. A summary of advantages and limitations of various water treatment technologies can be presented, with emphasis on new technologies (membrane filtration, UV, ozonation).

The presentation of water system principles should be followed by principles of risk assessment for drinking water systems, including system assessment, hazard identification, risk characterization, maximal and residual risk, and system improvements. Participants can be involved in discussions and case studies on applying the above principles to drinking water safety issues in their region.

The last part should review principles of verification of drinking water quality with discussions on the capability and limitations of common microbial and chemical water monitoring and interpretation of results to inform decision-making.

Recommended references: Allen et al. 2000; Hrudey and Leiss 2003; IWA 2004; Nadebaum et al. 2004; NHMRC 2004a; WHO 2004a; NHMRC 2004b

Drinking water safety strategy

The purpose of this module is to assist participants in developing drinking water safety strategies at the regional and provincial level. This training can be extended or adapted to environmental health managers and/or drinking water safety consultants depending on the extent they are involved in the process.

The module will review population health concepts and how they can be applied to drinking water safety. Furthermore, participants will be introduced to the process of developing health based targets and indicators for drinking water (types, application, and evaluation). The participants can then be assisted in a step-by-step development of a proposal for the regional/provincial drinking water safety strategy.

The process will be assisted by presenting drinking water best practices and quality management approaches to drinking water safety. Also, long-term solutions to safe drinking water such as water resources management, water regionalization, water reuse, and other topics of regional significance may be introduced for consideration in strategy development.

Recommended bibliography: Wanke et al. 1996; Saunders et al. 1996a; Saunders et al. 1996b; WHO 2004a; Hrudey 2005

Community Health Medicine students

Community health medical residents should receive training into basic principles of water safety that would facilitate their learning on the job as future medical officers of health. This can include principles for recognition and investigation of waterborne outbreaks,

basic water treatment principles, water treatment removal of pathogens , water safety barriers in a source to tap approach to drinking water safety (purpose, advantages and limitations), and basic principles of risk assessment and development of risk management plans for water systems.

Training delivery

Medical officers of health are very busy professionals whose responsibilities cover many areas. MOH workshops should last no more than one day. At least half of the time should be dedicated to case studies where to apply the knowledge and principles learned.

Workshops should include case studies and leave plenty room for discussions (which is a requirement for course recognition as continuing education credits for medical doctors). Case studies should actively involve participants in dealing with all aspects of a suspected waterborne hazard, such as performing a health risk assessment, incident management, risk communication, and development of preventive strategies.

For community medicine residents environmental health should be part of their training. A whole module might be dedicated to water safety or the drinking water safety principles presented above can be introduced as part of the environmental health module.

5. CONCLUSIONS

The capacity to provide consistently safe drinking water for everyone represents one of the greatest advances in population health in human history. Virtually eliminating drinking water as an exposure pathway for transmittable diseases, along with improvements in waste disposal and hygiene in affluent countries, are unequalled in effectiveness by any other public health interventions against the infectious diseases transmitted by the fecal-oral route that heavily plagued humanity (e.g. cholera, typhoid, dysentery, viral hepatitis A). In the transmission chain for these diseases, this intervention effectively assured there was one less source of disease to worry about. Moreover, by interrupting the fecal-oral circulation of pathogens in a community, drinking water treatment limited infectious disease endemicity in the population. So great has been the effect of this intervention that in affluent countries we barely remember the terrible epidemics that were once a periodic occurrence. We sometimes forget that contaminated drinking water has been in the past a regular source of illness and death by typhoid or cholera. Most Canadians have never witnessed a severe waterborne epidemic in their community during their lifetime. Canadians need to look at the situation in less affluent countries to remember how it once was in Canada.

I cannot help to think of the times when disease transmission by drinking water was a common occurrence. How fortunate we are now to be able to turn on the tap and drink the water without worrying about whether it will make us sick. As public health professionals, we must not forget that the basic causes that produced one epidemic after another in the past in every country have not disappeared. We are, however, much better at keeping pathogens under control and reducing factors of risk. Nevertheless, there is no reason to slacken our efforts. To keep up with population growth, agricultural development, globalization, faster travel and their effect on infectious disease transmission, we need to become even more efficient and to develop even better ways to protect population health.

A common problem with public health is that the general public cannot easily tell when we are doing our best; they would only know when we are failing to do so, because of the occurrence of otherwise preventable diseases. Drinking water safety faces the same challenge. People get so much used to the fact that the water they drink is safe, that they tend to forget the efforts it takes to make it so. The general public has come to regard drinking water as being essentially safe by default. They only remember that it might not be safe when events like the Walkerton tragedy occur.

In Canada we have the capacity to provide safe drinking water to all our residents. Not only are we blessed with abundant water sources, but we also have the expertise, technology and resources to assure drinking water quality to the highest standards. This mission is already facilitated by the work of the Canadian public health system and environmental agencies for over a century. Improvements in sanitation, waste disposal, hygiene and public education greatly reduced the available pathogen carriers and the impact on water sources. This is reflected in a reduction in the availability of pathogens that may contaminate our water supplies both in type (e.g. no typhoid, cholera) and in number, and less chemical contamination.

Public health and technological advances in water treatment have already proved that we can greatly reduce illness, suffering and death by improving drinking water quality. This represents excellent public health primary prevention. As a result, drinking water in large communities in Canada is as safe as it can be for most of the time. We now need quality management approaches to improve our capacity to consistently provide safe drinking water under both normal and challenging conditions, and more upstream interventions to address causes of water contamination. We also have to bring this higher standard to numerous small and private water supplies often operated by untrained individuals with inadequate or nonexistent safety barriers.

Assuring that drinking water provided to all citizens is safe is first and foremost a public health responsibility. While designing and supporting the technology that assures safety is an engineering challenge, assuring that water does not serve as a vehicle for the spread of disease remains a public health responsibility. Many participants in this study recognized safe drinking water as primarily a public health responsibility. What we need is to promote this understanding among all members of this profession including water operators, who represent the foundation for assuring delivery of safe drinking water.

The traditional public health approach to water safety has been to rely on end-of-pipe water quality monitoring and respond to adverse results by contacting responsible water operators to advise them on the significance of these results and the need to correct them, as well as to provide advice when needed. This approach came to be regarded as providing an appropriate check-up on water quality, at minimum expense. Not surprisingly then, many well-intentioned public health professionals believe that most of their activity in the field of water safety should be dedicated to doing precisely this.

The limitations of this approach have been discussed throughout this thesis. Relying on monitoring compliance with numerical water quality guidelines as the sole quality control measure cannot provide assurance that population health is protected from waterborne disease by drinking water. This insight is reflected in the new WHO (2004a) approach to drinking water management, as well as in the approach of countries like New Zealand and Australia, that focus on the development of water safety plans as the primary means for achieving drinking water safety, and use drinking water quality monitoring only as a check-up that these plans are working as intended.

Public health professionals in Canada need to receive more training in various aspects of risk management for water supplies in order to become more proactive and efficient in fulfilling their mandate to the public. While public health agencies continue to improve chronic disease prevention, infectious disease control, as well as to reduce exposure to environmental hazards by other paths, drinking water safety has received declining attention; but this is one area where excellence is achievable. We already know what we need to do and we have the technology to provide safe drinking water. Adoption of a quality management approach to drinking water safety based on risk management principles in the water industry would further benefit population health. Supportive legislation, regulations and policies, and proper training of public health professionals (including water operators) can assure consistently safe drinking water for all Canadians.

The interviews taken and questionnaire comments indicate that there are a few public health professionals who are beginning to recognize the limitations of the compliance monitoring approach as a primary means for achieving drinking water safety. This is consistent with the more recent trend in the past years within the water quality profession that promotes a more proactive approach, namely that drinking water safety is best assured by implementing an integrated risk management control system, based on assessing risk at all points throughout the water system.

Quite often, participants in this study expressed their frustration at not being more proactive. They should not be turned into clerks who have to reactively respond in an automatic manner to water monitoring results. They want to improve the situation in this field, and they should be helped to achieve this.

Risk management training would provide the tools to become more proactive in their activity. But this can only be supported by "educated" supervisory boards and supportive legislation that recognizes their job as being primarily the health risk management for drinking water supplies, and not merely water monitoring watchdogs. It requires understanding the major limitations and lack of efficiency of the current water monitoring approaches when it comes to protecting public from unsafe drinking water. We have to make sure that a water system runs properly first, then use treated water monitoring only as a confirmation that it is indeed so. Water monitoring for bacteria was never supposed to become the sole safety measure. It simply cannot be, if you look at its limitations (minuscule amount of water collected every now and then from a largely heterogeneous and changing medium, also prone to analytical errors and moreover, only testing for a limited range of pathogens, i.e. those that are sensitive to the disinfection method that kills coliforms). It is important that the training that these professionals receive in school and afterwards is truly put to work for public benefit. It is time to recognize that the role of public health professionals in the area of drinking water safety is primarily health risk management (with all the components), and that they need to be trained and supported to fulfill their duties.

Lastly, in seeking to improve population health protection from waterborne illness we must not forget our true priorities. Water treatment was introduced over a hundred years ago in order to limit pathogen transmission by drinking water which was bringing illness and death for hundreds, if not thousands, of people and not for aesthetics or concern over chemical contamination. Therefore, as we continue to research the health effects of chemical contaminants in drinking water, including by-products of disinfection, and develop ways to limit their presence in drinking water, we must not forget that pathogen control must never be compromised. While public health and health care professionals are increasingly concerned by the development of multiple-drug resistant bacteria, we should not forget that a simple and comparatively old disinfection process like chlorination is, if used properly, still very efficient to remove most bacterial pathogens, including drug-resistant strains.

During this research I came to appreciate the hard work and dedication of all public health professionals that I met or who responded to the questionnaire. Their responses had helped me to appreciate their training and sense of responsibility to the job that the public has entrusted them to do. The recommendations presented here are by no means aimed to criticize the hard work that they are doing. It is however my hope that this study will further assist them in assuring drinking water safety in the future.

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APPENDIX A

Interview Information Letter

APPENDIX B

Interview Consent Form

APPENDIX C

Questionnaire for Public Health Inspectors

Questionnaire

Please answer this questionnaire by checking the box next to the most appropriate answer and/or by writing your comments in the space provided.

Please provide an answer for each question, even if you would prefer that the question was worded differently.

You may explain any difficulty or concern that you had with any question in the comment space provided after each question.

1. What is (are) your current position(s) / title(s) [*without identifying yourself*]?

Please provide your job title only: ______________________

2. What would you consider to be the role and responsibilities of public health in ensuring safety of drinking water in your region?

Comments on this question:

3. How is this accomplished in practice? Please list specific actions:

Comments on this question:

4. How often do you have to respond to public inquiries on drinking water safety?

- ☐ *over 20 times /year*
- ☐ *10-20 times /year*
- ☐ *5-10 times / year*
- ☐ *1-4 times / year*
- ☐ *Never*

Comments on this question or your reasons for selecting your answer:

5. What are the most common concerns?

Comments on this question:

6. Personally, what would you regard as the most important concern for drinking water safety nowadays?

- ☐ *presence of chemical contaminants (natural or man-made; please specify examples below)*
- ☐ *presence of biological pathogens*
- ☐ *taste and odour complaints*
- ☐ *presence of chlorination by-products*
- ☐ *presence of other water treatment by-products*
- ☐ *other (please specify):* ____________________

Comments on this question or your reasons for selecting your answer:

7. In your opinion, which of the following drinking water related topics should be a part of PHIs / EHOs' training?

- ☐ *water treatment basics*
- ☐ *the multiple barrier approach*
- ☐ *water quality monitoring*
- ☐ *risk assessment for drinking water systems (e.g. sanitary surveys)*
- ☐ *risk management approaches for drinking water*
- ☐ *other (please specify):*

____

Comments on this question or your reasons for selecting your answer:

8. From your perspective, what do you believe to be the source of most errors in public health risk management actions regarding environmental contaminants in drinking water [*choose only one*]:

- ☐ *errors in sample collection*
- ☐ *errors in analytical technique and lab procedures*
- ☐ *errors in data interpretation*
- ☐ *errors in the decision-making process*

Comments on question 8. (see previous page) or your reasons for selecting your answer:

9. What is the lowest accuracy that you would accept from an analytical method, for a specific environmental contaminant, before you would be confident in taking a major risk management action (e.g. issuing a boil water advisory) based on this method indicating the presence of that environmental contaminant?

☐ *50%* ☐ *70%* ☐ *90%* ☐ *95%* ☐ *99%*

Comments on this question or your reasons for selecting your answer:

10. What is the lowest accuracy that you would accept from an analytical method, for a specific environmental contaminant, before you would be confident in not taking a major risk management action (e.g. not issuing a boil water advisory) based on this method indicating the absence of that environmental contaminant?

☐ *50%* ☐ *70%* ☐ *90%* ☐ *95%* ☐ *99%*

Comments on this question or your reasons for selecting your answer:

11. [*A hypothetical scenario*] Evidence for a Canadian city has indicated that in treated drinking water, a pathogen, say '*Giardia*', is truly present above the recognized standard methods detection limit, about once in every 10,000 water samples from the treated water distribution system.

Assume the analytical test for the pathogen has the following characteristics:

- **99.9% of tests will be positive for detection when the agent is truly present above the detection limit, and**
- **98% of tests will be negative for detection when the agent is truly not present above the detection limit.**

With these characteristics, given a positive result (detection) on the analytical test for the specified pathogen in the Canadian city, how likely do you think this positive result is true?
Provide either a probability estimate __ or indicate your scale of agreement below:

☐ *Almost certain (95 to 100%)*
☐ *Very likely (80 to 95%)*
☐ *More likely than not (50 to 80 %)*
☐ *Less likely than not (20 to 50%)*
☐ *Very unlikely (5 to 20%)*
☐ *Extremely unlikely (0 to 5%)*
☐ *No idea*

Comments on question 11. (see previous page) or your reasons for selecting your answer:

12. For the circumstances of question 11, if you have any remaining concerns about this evidence, how would you improve certainty for this result?

13. Does the Precautionary Principle influence your risk management decision-making?

☐ *Yes* ☐ *No* ☐ *Not sure*

Please also state what you believe the Precautionary Principle means.

14. Your comments on any related issues:

APPENDIX D

Questionnaire Information Letter

UNIVERSITY OF ALBERTA
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To ***Practicing Environmental Health Professional***

Re: **Drinking Water Safety & Risk Management for Public Health Professionals.**

Despite major advances in water treatment in the last 150 years, drinking water related outbreaks continue to occur. Current approaches have reduced their frequency and their impact on population in developed countries, but they are far from completely protecting the public. Incidents such as the Walkerton tragedy remind us of the serious challenges that public health professionals may face in ensuring public safety.

We are seeking your help for our research project on the role of public health professionals in ensuring drinking water safety and effective risk management. We ask your help to complete the attached questionnaire that should take you only 10 to 15 minutes to answer the 14 short questions. ***You should answer with your first instinct. You should not consult any of your colleagues or use any reference aids to answer.***

Please return your completed response in the prepaid postal envelope before September 30th, 2004. We will assure that all responses are completely anonymous. Our administrative assistant will permanently remove the number used for tracking responses before either Daniel or myself see any responses. No other person will ever be able to link your response to your name. The responses will be kept for at least 5 years after the study is done. They will be kept in a secure area (i.e. locked filing cabinet). Your name will never be used in any presentations or publications of the study results.

All responses received will be analyzed. Before the end of 2005, we will send a copy of the paper that we will write on this research to everyone who responds to our survey. This will provide you with insights on how to better achieve safety for drinking water and risk management approaches.

Thank you for considering our request and we sincerely hope that you will participate in this survey. In the case of concerns, complaints, or any consequences of this survey you may contact the Health Research Ethics Board at 492-9724.

Yours sincerely,

Daniel Jalba, MD	Steve E. Hrudey, PhD, DSc(Eng), PEng
MSc Environmental Health Student	Professor of Environmental Health Sciences

APPENDIX E

Summary of Interview Notes

I. Role and responsibilities for drinking water safety:

1. What are the major public health issues that public health has to address in your region?

Response notes:

- Disease surveillance
- Outbreak investigations
- Immunizations
- Chronic diseases prevention (cardiovascular diseases, diabetes)
- Lifestyle issues (tobacco, obesity)
- Certain notifiable infectious diseases: tuberculosis, hepatitis B and C, HIV/AIDS, other sexually transmitted infections
- Injury prevention
- Environmental health has variable importance, depending on the specific of each region. Food safety was always a major. Other issues were drinking water safety and recreational water safety, indoor/outdoor air quality, safe housing, environmental pollution (nuisance regulations, relevant to public health), and emergency response
- Seasonal issues: influenza, West Nile virus, enteric infections
- Migrant health (some regions)
- Other less common: animal bites, bottled water processing plants, etc.
- Specific to Australia: psittacosis, Murray River Fever, etc.

2. How would you define the role of public health in regards to ensuring drinking water safety. Please describe specific responsibilities that you understand for this role.

Response notes:

- The respective provincial Health Protection Act (or equivalent) does not normally have specific water safety provisions for public health authorities.
- Some provinces or Australia states have adopted specific acts (e.g. Drinking Water Protection Act in British Columbia; Safe Drinking Water Act in Ontario; Safe Drinking Water Act in Victoria, Australia)
- Yet other provinces rely on general provisions of the Public Health Act and its regulations and on more specific reference documents.
- Interviewees generally defined their role as protecting public health from water related disease
- However, understanding of specific responsibilities varies widely:
    - ***From:*** follow-up on adverse water results (i.e. coliforms present in treated water) and investigate water quality complaints that may suggest potential health risk (e.g. turbidity)
    - ***To:*** catchment to consumer approach, i.e. involve in watershed management; assure source protection, adequate water treatment

    - and disinfection, maintain water quality in the distribution; ensure regular water quality monitoring and follow-up
    - Where there was no specific mandate to be proactive, then there was involvement in stakeholder committees for safe water and/or consultative role, and/or community education
- Lack of resources and staff, and of specific safe water legislation are usually cited as major limitations to being proactive
- public health is often more involved with small systems, whereas large systems would only be contacted in case of major events (e.g. suspected waterborne outbreak, positive coliform tests, high turbidity, water quality complaints)
- However, even with small systems there is rarely a consistently proactive approach (more random and reactive).

3. What actions do you take to ensure the safety of drinking water in your region?

Response notes:

- Actions also depend on the existence of specific safe water legislation
- In the absence of it:
    - Facilitate submission of water samples to accredited labs (for small systems)
    - Follow-up on adverse water results: interpretation, investigate cause, advise on solutions to correct: alternative water sources, treatment options; public health more actively involved for small systems, generally consultative role for municipal systems
    - Occasional spot checking, samples collected directly by the PHI (coliforms, chlorine residual); where there is a concern, water samples collected also for other non-routine analyses (chemicals, metals); where field kits available, also on-site testing of chlorine residual, pH, turbidity, etc.
    - Issue boil water or do not drink advisories /orders
    - Public education on safe water, usually for private well owners (campaigns, pamphlets)
    - Investigate complaints
    - Site visits / inspections, usually targeted by positive coliform results or suspicion of contamination
    - Consultative role for other agencies and water operators
    - Some RHAs with more resources try to be more proactive, even in the absence of legislation: create an inventory of water systems to keep track of water testing results, current state of system and upgrades; involve in risk assessments and development of risk management plans for municipal and small water systems; get more involved in investigation of municipal water issues along with Environment, advocate for watershed protection, involved in emergency planning for water systems, etc.
- Where specific legislation was present:

- Maintain an inventory of water systems and of adverse results (done in Australia, in process to be completed in British Columbia and in some parts of Alberta and Ontario)
- Involved in all aspects of safe water provision (British Columbia):
- watershed management and source protection,
- water treatment and disinfection,
- maintain water quality in the distribution,
- ensure regular monitoring and follow-up,
- water operator training and certification,
- community education

II. Approaches to ensure drinking water safety:

4. How often do you need to answer inquiries about drinking water safety?

Response notes:

- Most rural PHIs and PHI water specialists would respond to drinking water inquiries at least on a daily basis
- EH managers and city PHIs respond less often, depending on expertise and circumstances, usually weekly
- MOHs have much more diverse responsibilities, would normally rely on their EH staff to address concerns; may get involved on a monthly basis, except for particularly busy seasons (e.g. spring), that requires more BWAs

5. What are the most common concerns?

Response notes:

- Concerns are often driven by what is tested or by suspected contamination due to proximity with agricultural or industrial developments
- Most concerns are related to the adverse bacteriological results for treated water samples (coliforms present)
- Concerns often come from the system owner (for private or small systems) or from the public (for municipal systems)
- Questions relate to test interpretation, significance, how to correct the problem (quick fix!), how to protect own health
- Other concerns: water aesthetics (taste, odour, turbidity, discoloration), illness of suspected waterborne source (e.g. *Giardia*), significance and duration of a BWA, water sampling (how to, what), system maintenance (including tanks), effects of agricultural or industrial developments on water source, etc.
- Other pathogens/chemicals: THMs and other DBPs, protozoa (*Giardia*, *Cryptosporidium*), naturally or artificially occurring chemicals (arsenic, lead, nitrates/nitrites, selenium, fluoride, barium, sulphates), *H. pylori*, algae (blue-green, other algae, algotoxins), pesticides, pharmaceuticals (antibiotics, hormones), hormone-like compounds/pollutants

- Rare/regional-specific: sour gas contamination, hydrocarbons, sulphates
- In Australia, in addition to the above: wastewater reuse for agricultural or domestic purposes

6. Who responds to potential concerns about drinking water safety?

Response notes:

- The frontline staff is the area PHI, taking most questions related to coliform test results, water treatment, source protection (e.g. from sewage)
- More specific questions are forwarded to the water specialist or senior PHIs (when available), or to the EH manager
- The MOH answers questions related to health effects, health risk, coming from public, local physicians, media, other agencies (e.g. environment).

7. Describe the resources that your RHA dedicates to water quality issues.

Response notes:

- Largely depends on existence of specific water safety legislation and overall resources dedicated to public health or environmental health
- It is also influenced by need, but it depends how you identify and define "need"
- Full time equivalents (FTE) on water safety: 0.5 (most common) – 2.5 (and up to 5.0 in British Columbia)
- See next question for specialized staff

8. Do you have a dedicated employee for this task? What training does s/he have? If no, what level of training would you say the PHIs/EHOs generally have in this area?

Response notes:

- Depends on resources and priorities (or vice versa)
- Also apparently depends on the size of the region; however, when asked, most interviewees would actually see the need and scope for a dedicated full-time staff.
- Large RHAs would have dedicated water consultants within their EH team
- Other RHAs may have water specialists (e.g. EHO specialized in water safety, but with regular EHO responsibilities)
- Other RHAs would not have any specialized person, rely on peer consultation
- Training usually consists in EH school, practicum and on-the-job training, plus attendance of specific workshops and conferences organized by professional associations or other agencies (e.g. environment)

9. What is the after hours / weekend response capacity to water quality concerns (in terms of resources, staff, etc.)? How does it work in practice?

Response notes:

- 24 hour public health response lines /paging are available for EH / water safety concerns in most provinces/regions. In other regions there may be a paging system.
- Some regions only have MOH on call, others also have EHO / public health nurse on call (by rotation)
- The response line is available to other professionals, agencies, municipal water operators
- Public may or may not have direct access (secondary lines)
- The person on call will follow adverse water results protocol, will call an EHO to investigate if necessary

10. Describe the public health relationship with water systems professionals in your region. How often do you need to consult with them?

Response notes:

- Varies widely, depending on public health mandate in the respective province
- In British Columbia: public health hires their own public health engineers and drinking water officers, licenses and inspects water systems, trains operators – very close relationship
- In Quebec: public health has more of a consultative role, Ministry of Environment licenses, inspects and trains; public health has no direct contact with operators except in extreme circumstances
- In Alberta and most other provinces and Australia, Department of Environment licenses municipal systems and systems over 15 connections, etc. The answers below refer to these provinces, unless otherwise specified.
- public health relation with municipal systems or Department of Environment mostly consists on two-way communication on problems that potentially may impact water safety (e.g. chlorination not working, filtration inefficient, cannot control turbidity) and to discuss the opportunity for public health advisories (BWA, do not drink advisories); other drinking water concerns may be discussed, if Environment sees a need for public health input, but there is no legislation to require that.
- public health is involved more closely with small systems: inspection, advice, facilitate sample analysis and interpretation
- Involvement as consultant for public health risks depends on individual expertise
- Not consistently involved in licensing and license renewal for regulated systems
- Sometimes, asked for opinion if issue relates directly to public health concerns
- public health would collect some grab samples of treated water by themselves and have them tested – more a check-up, for municipal systems

- In most provinces, public health is the agency that is closest in contact with small systems operators and private systems owners
- Also, by default, would be responsible for any other systems that are not regulated, transient or non-transient (e.g. fairs, campgrounds, trailer parks, Métis settlements)
- Large RHAs, usually including a large city, would have resources to hire dedicated water consultants that stay in regular contact with municipal water system staff (e.g. Edmonton, Calgary)
- For other RHAs periodic contact (e.g. weekly to monthly) is common, it usually depends on personal experience of public health staff, but time availability is limited, since they cannot hire a dedicated person.

11. What kind of problems does public health encounter in relation to ensuring drinking water safety?

Response notes:

- Drinking water safety being given low priority in local and provincial budgets, compared to other competing issues
- Lack of manpower and resources for environmental health activity
- (some provinces, e.g. Alberta) Lack of specific legislation to mandate public health role in drinking water safety (as it does with safe housing or recreational water in Alberta)
- In some regions, understaffing of municipal water systems due to prevalence of other priorities
- Untrained, insufficiently trained or improperly trained water operators (particularly for small systems)
- In some provinces, public health has limited input in water operator training
- Insufficient financial resources to upgrade water systems to current standards (common for small and medium size systems)
- Seasonal variations in water source quantity and quality, leading to challenges to water systems (e.g. drought, spring runoff, algal development)
- Sustainability of water source (Southern Alberta and Australia)
- Watershed contamination from:
  - Natural chemical contamination, particularly for groundwater sources (e.g. arsenic, boron, selenium, barium, fluoride)
  - Agricultural developments: manure (biological contamination), nitrates, pesticides, water body eutrophication (fertilizers), etc.
  - Industry (e.g. trichloroethylene, lead, hydrocarbons)
  - Any development that may produce oil or fuel spills (e.g. forestry)
  - Public health has limited control over watershed developments that may impact water safety
- Sewage contamination is the most common form of contamination and may occur at various stages in the drinking water production, due to: release in the watershed/water source, old sewage systems not leak proof or too close to water source, cross-connections, etc.

- Old water treatment equipment, not very effective against new and emerging pathogens (e.g. protozoa). Often lack of resources to upgrade, but also low-priority for owners.
- Old distribution systems, with infiltrations and cross-connections
- Some provinces offer free water testing, others not. Either way, not many owners of small systems would test their water regularly
- Recurring, ongoing BWAs (sometimes for years), due to consistent positive coliform results
- Difficulties to investigate water systems in industrial developments
- Jurisdictional issues in regions with mixed aboriginal/non-aboriginal population
- Lack of expertise for consultation by public health professionals when needed
- Last, but definitely not least, many problems relate to the functioning of small water systems (regulated or not, private or not):
    - Many such systems (often old systems) have minimal treatment/disinfection and no regular monitoring, particularly if not specifically regulated
    - Contamination of water source with sewage, chemicals (wells) or algae (dugouts) is common
    - Most such systems are poorly prepared to deal with more unusual contaminants (e.g. protozoan pathogens)
    - Owner resistance to correct deficiencies (implement proper treatment, change water source), for various reasons (financial, health or taste and odour concerns, not agree there is a problem, etc.)
    - Occasionally, water well drilled through septic field (lack of communication)
    - Lack of financial resources is often invoked as a major limitation to improvements
    - However, many preventive measures can be taken with minimal investment
    - Transient water systems (e.g. forestry camps, recreational campgrounds, fairs, restaurants, summer cottages) are particularly vulnerable, since there is no interest to invest on secure water supplies, from either owner or temporary residents
    - Improperly trained operators, no requirement of formal training or certification for operators of non-regulated systems.

12. What would be your priorities for receiving assistance for dealing with the problems identified above?

Response notes:

- Additional staff, resources (to improve expertise, field capability, field testing kits, do more spot testing, etc.); in particular, funding to afford a full-time water consultant
- Training – see next questions

- Clear jurisdiction and roles of every stakeholder (public health, Environment, other agencies, municipality)
- Better communication between public health, regulatory agency and municipalities, e.g. to share concerns when licensing or renewing licenses for a water system
- Free water sampling for small systems (where not available)
- (some provinces) Strengthening the Public Health Act or adoption of more specific legislation (e.g. safe water act)
- Need resource persons to contact when needed, co-operation with other RHAs, institutes, universities to make use of their expertise, information resources
- Develop a water systems database with GIS link (system description, water sampling results and risk level)
- More access to training opportunities, specific conferences, etc.
- Better analytical capability for heavy metals, toxic organics, biological pathogens (protozoa, viruses), etc.
- More research on industrial pollutants
- Sometimes difficult to get qualified people (for inspection, risk assessment, public health engineers, etc.)
- Management of water scarcity

III. Training needs

13. What would you consider the key issues to ensure drinking water safety? Please elaborate ...

Response notes:

- Understand that current major reliance on water monitoring for prevention is neither cost efficient nor very effective (particularly for small systems)
- Catchment to consumer risk assessment approach
- Development of appropriate risk management plans
- Include emergency response *and* contingency plans
- Use adequate water sources
- Water regionalisation when local resources insufficient or no adequate water source available
- Multiple barrier approach to prevention and protection
- Good understanding of water monitoring and significance of results
- Empower public health to have a real say on watershed developments that may impact water quality
- Water operator training consistent and adjusted to expectations to perform (i.e. small systems specific training)
- Requirement of formal training and possibly certification for all operators that respond for a public water system. Training for small system operators could be done by either Environment or PHIs.

14. What would you regard as the major aspects that public health professionals need to know in order to be assured that drinking water is safe for the public? Please be specific in terms of water treatment process, water safety barriers, water monitoring, disease surveillance, etc.

Response notes:

- Understand aspects of water system infrastructure and process relevant to water safety
- Understand different water pathogens, specific aspects and significance of their presence in treated water (e.g. *Cryptosporidium*)
- Understand water system monitoring and significance of results for water safety (e.g. check of water safety barrier efficiency,)
- Able to perform health risk assessment for various contaminants
- Understand that water safety is a multi-step process and the need for multiple barrier approach: purpose of each barrier, that each step is 100% needed, use of multiple barriers for the same purpose (e.g. chlorination and UV for disinfection)
- Perform watershed to consumer risk assessments for both large and small water systems; understand ecology issues that may impact water safety (e.g. runoff, eutrophication)
- Develop risk management plans for a water system (either large or small or both, depending on needs)
- Develop emergency response and contingency plans
- Specific waterborne outbreak investigation skills
- Risk communication (v. important!!)
- Computer skills, use of water systems database

15. Which of these aspects would you regard as requiring more focus for public health training?

Response notes:

- PHIs: (water monitoring generally well covered in school), drinking water guidelines and standards, risk assessment and risk management for contaminants, risk assessment for water systems, development of risk management plans for a water system, risk communication, water treatment basics and advantages and limitations of new technologies, elements of waste water management (particularly for private sources), recognition and investigation of waterborne outbreaks.
- MOHs: drinking water guidelines and standards, high-level risk assessment and risk management with case studies and opportunity for discussions, updates on water treatment technology and approaches
- Community medicine residents need to receive some specific basic water safety instruction that prepares them for MOH positions (most interviewees never got that in medical school): recognition and investigation of waterborne outbreaks, basic water treatment, risk assessment and development of risk management plans for water systems, and safety barriers (purpose, advantages and limitations).

16. What approach would you suggest in order to accomplish these training needs?

Response notes:

- Different approaches all acceptable, will have to be adjusted to circumstances and financial limitations; user friendly, consider competing responsibilities (e.g. modular)
- Involve experienced practitioners (MOHs, PHIs, water operators)
- Define a standard of minimal knowledge and training in water safety across the province
- Short-term workshops; include workshops in continuing education credit schemes for MOHs (and for PHIs if they are implemented in the future).
- Specialized university course for more advanced knowledge
- Online courses may have limited efficiency, since direct peer-to-peer exchange of experience is very appreciated (also may be limited by lack of computer infrastructure in some provinces/regions)

17. What are the most critical constraints that you face in pursuing these?

Response notes:

- Time availability, competing responsibilities – most often
- Money – some provinces, some RHAs
- Lack of expert support, for consultation or to organize training.

APPENDIX F

Questionnaire Comments

Question 2:

- The responsibilities are hard to accomplish, with all areas of responsibility under our mandate. Should be a separate department.
- We are involved in all aspects with the new Drinking Water Protection Act in British Columbia. Too many responsibilities to have them listed. We have it all covered I think.
- public vs. private water systems?
- Public health must take responsibility for approvals of public water (not Alberta Environment), i.e. groundwater under direct influence of surface water.
- Health and only health should be in the forefront of providing drinking water. Ontario showed that. Environmental bodies don't have knowledge on this.
- Alberta Environment approves and also monitors municipal water.
- We work as part of a team along with drinking water officers and public health engineers – we have to work together to be effective.
- Question is too general – many answers
- No regulation or requirement for well drillers to contact health or register wells. Public doesn't know or goes ahead without consulting
- Oversight of Alberta Environment licensed systems as well as Alberta Environment operations (they continue to not even ensure compliance with their own legislation – they admit severe understaffing and inability to ensure their own legislation is enforced)
- I would include everything from source to tap as areas that require monitoring, including water bottling & refill locations. I know this is not the case in reality.
- Customers on wells and cistern require more attention than municipal supplies.
- A minimum sampling frequency misses a lot.

Question 3:

- Government (Health Minister, others) are not taking serious enough; won't back chlorination of ground water sources.
- Major flaw: we are NOT currently involved in the process when water systems are designed or installed.
- Regulations must support the work being done.
- Poorly. With all the other areas the PHI is responsible for, there is precious little time and training set aside for this area. A "specialized" department should assume all responsibility for drinking water (e.g. Alberta Environment or a new governmental department).
- Currently Environment is the lead agency for licensing. Their mandate and Health do not always have the same priority. Time is a major issue in site investigation/ resampling. More positions are required to commit to water issues.
- Generally day to day – very little. The municipality operates the system and monitors safety.
- Not very well.
- It doesn't happen. Especially not at water bottling plants. Other offices may be responsible for well water in rural areas, but in the city is 100% faith.
- No idea if operators properly trained or not. Routine inspections not done; only on complaint basis.

- The ideal method for source-to-tap approach is to work with other agencies; however there are a multitude of competing interests (e.g. desire to sell lots on Crown reservoir lakes, the new sewerage disposal regulation) that get in the way.

Question 4:

Option selected	Comments:
> 20/year	- vast majority of concerns are for private drinking water sources, e.g. wells (5 respondents). - Approximately 15-20 times/ week - At least twice a week - because our office has specialized, regular EHOs do not respond to the calls. We have a Water EHO that deals with all drinking water issues. - if the public was more aware of drinking water safety issues, they would ask more questions (public & private systems). - we have many remote camps in our area, plus a BWO was issued for a small community. - in my previous position in a rural health unit. - often more than 20 times/month (2 respondents) - in the past 10 months we had 1 precautionary BWA and 1 BWA. Notification of the community members was not done in a cohesive manner: many people were not aware of the advisory for several days. - area with a lot of small, untreated systems. - due to contact with clients regarding positive enteric lab reports. - dealing with public results weekly, if not daily. 80% of the inquiries revolve around safety. The 20% relate to supply and chemical quality. - as a frontline worker in British Columbia, I get 10-20 times/week. - I receive at least 2 calls/ month regarding water, often from new people coming into the area (we have many systems on boil advisories and I have to explain what that means, and what to do about it). - most rural inspectors probably consult on water issues over 100 times/ year (2 respondents), though we don't seem to get any credit for it. - my staff have 500 water systems. - I respond to hundreds of inquiries per year. - perhaps much more than this (at least 20 just over summer). - public water systems: 1-4x/year; private water supplies: >20x/year. - 10-20 times a month. - 11 municipal systems , all somewhat different. - I respond to public inquiries regarding drinking water safety almost daily. - I work specifically in the drinking water program in my health region. All drinking water complaints/questions/concerns are directed to me or one of the 5 drinking water inspectors. - only a small % of inquiries are expressed as complaints.
10-20/year	- this is part of my duties as of March 1, 2004. - 1-2 calls per month - we have 2 water specialists in our region who handle the bulk of the inquiries.

	- I personally respond to questions on bottled water. Rural inspectors usually respond to questions on private systems. The water consultant usually responds to municipal water questions and issues. Rural inspectors will respond to many more inquiries than urban systems.
5-10/year	- in my office we have specific inspectors that deal with the bulk of the water system issues, so my activities in these matters are limited. - depends on the coverage area: if the area has more rural component – more questions. - aesthetics mainly. - when I worked in a rural area, I had many calls weekly on water safety. Now I am in an area on municipal water. - there are other staff who field public inquiries. Otherwise the number would be higher. - In larger centres an assigned EHO is responsible for drinking water issues. In smaller centres or rural Alberta, all EHOs respond to inquiries. The question should distinguish the difference between private & public water supplies.
1-4/year	- I am not a specialist in this area; they would be over 20 times/ year. - I only get a few of the inquiries. The bulk goes to the water specialist (3 respondents); or the other district inspectors. - varies according to what district is looked after. - our region has drinking water specialists who look after these sort of things. (2 respondents) - I am a restaurant inspector in the city. I have very few establishments that have their own private systems. - when I was in a regular district. - we have received complaints from people who perceive a problem. Often, assurance is all that is required.
Never	- all drinking water issues are directed to our water specialist PHI. General PHIs do not deal with water issues, unless related to a food premise or other inspected establishments. - I do not handle water results in our region. Another inspector does all of them.

Question 5:

- the majority of concerns come from owners of private water systems (2 respondents)
- concerns can be regionally specific (e.g. high arsenic in some areas)
- I always advise water sample for bacterial and chemical quality to landowners prior to oil industry activity
- lack of staff is my concern
- the general public seems to think that surface water (i.e. streams in the mountains) are safe to drink without treatment
- inadequate training of PHIs to new changes in legislation
- most inquiries are referral driven, through an application to subdivide or develop land.

Question 6:

6.1. Chemical contaminants:

- chemical contaminants (fertilizers, pesticides, etc.) are a major concern because of public lack of knowledge on health effects, plus limitations of treatment systems that can remove them (costs, monitoring, maintenance).
- arsenic (3 respondents), hydrogen sulphide, cyanide, benzene, malathion, mercury, nitrates, lead, fluoride, uranium.
- public more concerned about toxicological effects of chemicals in water (2 respondents); public concern becomes more important in public health.
- more difficult to remove.
- e.g. pharmaceuticals, antibiotics, hormones.
- it is relatively easy to make bacteriologically safe water, but very difficult to remove chemical contaminants.
- we don't have the analytical capability to test for them at governmental level – have to send to other agencies.
- increase in industrial chemicals, manufacturing firms, etc.
- rural: arsenic, followed closely by fecal coliforms; urban: chlorine residuals.
- we are focusing on biological pathogens and have fairly good controls, little is still being done in the area of chemical contaminants.
- it is easier to solve biological factors.

6.2. Biological pathogens

- chemicals often require prolonged exposure to cause health effects, whereas for biological pathogens 1 single exposure can make you ill (3 respondents); chemicals are a long term concern (e.g. leukemia) (2 respondents).
- chemical is close second (2 respondents); the cost of testing makes it hard to pinpoint any contamination.
- chemicals would be more of a concern depending on chemical and its levels.
- this is not the greatest concern of the public (chemicals are), but it is my greatest concern (2 respondents).
- this is a regional issue (3 respondents). Here (e.g. Northern British Columbia) we have biological pathogens, but in an industrial area (e.g. Toronto) it could be man-made chemicals (plastic by-products, pharmaceuticals, etc.); in rural communities most use well water which is more prone to bacteriological contamination than DBPs; many supplies in this area are surface supplies, many without any type of treatment (dugouts, ponds, lakes, rivers, irrigation).
- need to specify, is this regarding public or private supplies. Private assume their well is good and are fairly ignorant on risks and maintenance (2 respondents). Hard to convince as sometimes they are the 3rd generation to use it.
- parasites are particularly hard to remove.
- groundwater contamination from agricultural & industrial practices.
- personally, all of these are important, but the consumer only knows about bacteria.
- we don't have enough information on chemical and DBP levels in water.
- will have the largest direct impact on population; potential for disease outbreaks.
- I generally do not receive calls regarding other issues listed.

- most water tests relate to total coliforms or *E.coli*, therefore most discussions with public relates to these issues.
- most complaints related to taste and odour.
- still working on multi-barrier approach.
- H7: O157.
- drinking water has been ignored for a long time in Saskatchewan, so we need to start at the basics.
- a few other respondents mentioned in their comments that their specific area is more prone to biological pathogens, rather than this being a general concern.

6.4. Chlorination by-products

- drinking water concerns depend on source, type of disinfection, knowledge of suppliers and presence of emergency plans. I think in the lower mainland the most important concern is presence of chlorination by-products.
- essentially we consider most enteric disease to come from food; I think we need to address chlorination by-products; can THMs be formed in the gastrointestinal tract?

6.6. Other

- value, cost vs. safety. The public wants safe water from the tap, yet they won't pay for public system but for a much greater cost to buy bottled, etc. water.
- source protection (3 respondents), from both industry and domestic users; if you have good quality source water most of the other concerns listed are reduced). We should emphasize water protection, especially waste management.
- lack of multiple barriers for removal of biological pathogens. (2 respondents); most of the systems I inspect have only basic disinfection (no filtration, no additional treatment/ disinfection); British Columbia has numerous outbreaks of *Giardia*, simple disinfection is compromised during turbidity events.
- operator knowledge and understanding of consequences of unsafe operation (2 respondents) and funding to maintain these systems.
- public education.
- depends on where you live, the water source and type of treatment (e.g. in Vancouver we are concerned about chlorination by-products and pathogens, in Bowen district people are concerned about As, on the Fraser Valley the concerns are nitrogen & pesticides).
- shift away from Health in regulations (shift from Health to Environment, Infrastructure, etc. within regulatory structure).
- lack of fluoridation.

Question 7:

- All of these should be part of the training (5 respondents)
- All of these are taught at Ryerson/ Concordia (4 respondents)
- The first 3 are already part of the training. The boxes I checked should be more thoroughly covered.
- Having just finished school and now working in field I realize how little we learned about water, especially hands-on. I feel not very confident when inspecting water systems.

- PHIs require much more than the training they are currently receiving. Water treatment technology continues to improve and in order to be able to provide usable info to our operators we need to be well educated.
- PHIs/EHOs have to understand what they are really looking for during drinking water system inspections.
- The expectation of frontline staff in British Columbia is to be conversant on all these topics.
- Water quality is only now becoming an increased issue due to Walkerton, etc., with increases in funding & positions. Thorough training needs to be provided in all areas.
- All are important. For rural EHOs, knowing how to assist small/private systems who have little/ no money is very important.
- All are needed, but perhaps the most important is the ability to explain why I need to spend money to protect my family when we have used untreated dugout water for years.
-In order to effectively evaluate risks in a water system, knowledge in all of these areas is essential.
- We need to know what to look for other than deadlines. We need courses/ in-services/ workshops!
- Ongoing education will help us be informed of technological advances and emerging issues with our water.
- All of these would be useful. Continuing education also very important. We need more opportunities for education & all regions to support their PHIs in attendance.
- Water quality monitoring doesn't take much training. Risk assessment for drinking water systems and other things along those lines may "step on toes" of agencies like Alberta Environment, who are supposed to be doing inspections and evaluating water treatment plants.
- The older designs do not handle the newer methods of treatment.
- What is multiple barrier approach?

Question 8:

8.1 Errors in sample collection

- poor sampling technique is often responsible for many false positive results (4 respondents)
- sample requisitions inadequately completed (2 respondents) and untimely sample delivery by governmental courier (2 respondents); miscommunication between operators, lab, PHI and MOH; sample contamination when shipping over long distances.
- high rate of negative samples following positive ones prove the high likelihood of sampling errors
- current sampling requirements provide an incomplete picture
- have to consider synergistic effects of chemicals in drinking water.
- confusing question: is it from regulatory or operator point of view?

8.2. Errors in analytical technique and lab procedures

- none relevant.

8.3. Errors in data interpretation

- interpretation of what data actually mean, very much guessing; poor understanding and interpretation of total vs. fecal coliform results and of low total counts (2 respondents); **coliforms as indicators involve a wide range of interpretation from region to region.**
- people may be unsure regarding what steps to take when faced with adverse results.
- lack of communication between operators and public health unit
- interpretation of data includes knowledge of sampling techniques; sampling and lab analyses largely under some quality control criteria.

8.4. Errors in the decision-making process

- a few respondents appreciated that the decision-making process includes the previous options.
- decision-making may often be influenced more by public risk perception than scientific fact (5 respondents)
- lack of standardization and technical training on drinking water quality among public health professionals (2 respondents)
- the source of errors varies with type of contaminant (i.e. different for biological vs. chemical)
- a thorough review of water system needs to be done before actions are recommended.
- chemical results for drinking water are less reliable because we often use private as opposed to public labs (unlike for bacteria)
- untimely results due to lab priorities, may be too late in an outbreak.
- there is a lack of political will to address issues confronting water systems.
- most operators in British Columbia are not properly trained
- I don't believe these 4 options are adequate in assessing health risk management errors (2 respondents, no suggestions); not many errors occur in the offered categories.
- faulty data interpretation often results in decision-making errors; what do the results mean in terms of public health.
- lack of information; constant change of protocols and new information make it difficult to make informed decisions.
- we depend on who and what department collects the samples. Health does not always have faith in Environment and vice versa. Health expects 100% while others have allowable limits sometimes determined by "dollars".

Question 9:

Option	Comments:
99%	- issuance of a BWA is usually based on more information than just one lab result (2 respondents). But accuracy percentages are not shared – results are presumed to be highly accurate. - public vs. private. - a fecal positive sample would warrant a BWA even if there is a chance it's a false positive. Prevention is better than waiting for a resample. - labs (I've worked in one) now have the ability to get results as close

	to 99%, leaving 1% margin for error. - current technology and accredited labs result in a high accuracy. - I defer to statistical experts as to acceptable confidence intervals. Would also depend on contaminant. - obviously we all want tests that are as accurate as possible but if the test was only 50% accurate, I still would not hesitate to taking action to protect the public. I would rather err on the side of safety than assume it's a testing error. - often, if we have doubts, we take split samples. - not sure what you are asking. - I would have preferred the answer "none".
95%	- issuing a BWO is a serious action; must consider the parameter. - although I may not be highly "confident" at this accuracy level & may take action anyway depending on contaminants & risks. - a BWO, etc. greatly affect a person's business & reputation. It is important to have good info before acting. - seems reasonable, would catch all but very low amounts of bacterial contaminants. - but it really depends on the contaminant. Some you may be willing to accept lower accuracy due to high risk or high level of contamination. - there area few cases where false positives were reported & further tests have indicated no coliforms. - I want to be very sure that the contaminant is really there – it's not black & white – there are many things that need to be checked out before a BWA is placed on a system - you can't rely on a lab test only. - instrumental limitation; human error. - it is hard to get 99% accuracy, but if it is not accurate, legally it would be hard to take action. Should be the most accurate method for each particular contaminant. - BWAs are issued after looking at all factors – normally you don't rely on 1 indicator. - my choice also depends on cost. If the extra cost of being more certain is low then the 99% certainty should be selected. Also, I do not know what the accuracy rating is for the current analytical methods use by prov lab. - I would not wish to needlessly alarm the public. - lab takes care of lab error. I don't know what the sampling error is for each sample. In truth I don't consider this issue. - to be meaningful and have confidence in the result this would be minimum acceptable. - preliminary results are not the most accurate.
90%	- Testing needs to be accurate, to avoid false results leading to panic, public outrage and unnecessary economic burden, yet, at the same time, more importantly public health needs to be maintained. 90% is a reasonable margin to initiate safety measures. - I want to be sure of something before I inconvenience the population. - Assume that accepted analytical methods would be used to make any decisions. - depends on the parameter (some are more hazardous than others); also on other factors: no. of samples, sampling method, etc. - If *E.coli* – should be 99%. Remember boil advisory should be very

	well explained. - May be difficult to ask for more than 90% in terms of costs and time of tests. - depends on contaminant, its seriousness, and whether it is a concern for chronic exposure or acute. - varies depending on contaminant (biological vs. chemical). - issuing a BWA is not based on only 1 factor such as accuracy of analysis. Many factors are considered in issuing or initiation of management action. (3 respondents) - resamples are always conducted prior to escalated action to rule out sample error (often parallel resample). - depends on contaminant. You have to be very certain before taking major RM action to avoid liability and misinterpretation. - depends also on contaminant, I may take action even at 50% if there is concern. - what I meant was I expect the lab to have at least 90% accuracy rate. - not sure (2 respondents).
70%	- this accuracy would be sufficient to warrant some RM action. If lab analysis proves not present, great, but better to act on possibility.
50%	- If a test having 50% accuracy showed positive for *E.coli*, I would take immediate risk management action until new tests could be completed. - an environmental contaminant in drinking water has the potential to cause major damage, thus even lower accuracy may warrant action. Better to be safe than sorry … - far too much emphasis is placed on analytical precision. Many major decisions are made before lab data is available. The goal is to be proactive.
Missing	- Our actions that we take are based on presence or absence of the parameter testing for and comparing it to CDWQG or established levels. We trust that our provincial lab would have a relatively high accuracy, that tests are done right and would not deal with a risk this way (in percentages). - I don't do this in my scope of practice. - I would ask the specialist who knows. - too vague

Question 10:

Option	Comments:
99%	- need to err on the side of caution and safety. (2 respondents) - issuance of a BWA is usually based on more information than just one lab result (.. respondents). But accuracy percentages are not shared – results are presumed to be highly accurate. - it is important to take a proactive approach. - I defer to statistical experts as to acceptable confidence intervals. Would also depend on contaminant. - obviously we all want tests that are as accurate as possible but if the test was only 50% accurate, I still would not hesitate to taking action to protect the public. I would rather err on the side of safety than assume it's a testing error. - the higher, the better; a BWA is not issued without good reason.

	- I would want to be very sure there is no risk before not taking action. - this is a redundant question: same as question #9.
95%	- although I may not be highly "confident" at this accuracy level & may take action anyway depending on contaminants & risks. - water has become a political hot bed. The public wants to be protected from everything and have gone away from any personal responsibility. - I don't know how accurate various tests can be, so difficult to answer. - the sampling conditions would matter; also the source of water: is there any *E.coli* in raw water?, etc. - err on the side of caution - sampling history would also be used in this decision. - to be meaningful and have confidence in the result this would be minimum acceptable. - +/- 2 SD was acceptable for most lab results when I worked in a lab. - depends on contaminant and associated factors.
90%	- this is difficult, must consider the parameter. - Assume that accepted analytical methods would be used to make any decisions. - depends on the parameter (some are more hazardous than others); also on other factors: no. of samples, sampling method, etc. If I thought there was a chance of risk despite clear results, I might still take action: results may not be the only consideration. - situation dependant, would prefer higher. - other contributing factors. - action would still be taken if the test often gives false negatives (e.g. *Cryptosporidium*); this depends on the specific test being done. - I don't know the accuracy of the current methods that our labs use. - the possibility of contaminant presence at 10% is high enough to be an acceptable risk.
70%	- depends on contaminant. You have to be very certain before taking major RM action to avoid liability and misinterpretation. But, in most cases, better err to the side of caution. (2 respondents)
50%	- I want to be sure of something before I inconvenience the population. If I sign off that something is OK, I want it to be OK. - labs (I've worked in one) now have the ability to get results as close to 99%, leaving 1% margin for error. - it is a bit unclear: is this test the only one available? - far too much emphasis is placed on monitoring specific environmental contaminants.
Missing	- Our actions that we take are based on presence or absence of the parameter testing for and comparing it to CDWQG or established levels. We trust that our provincial lab would have a relatively high accuracy, that tests are done right and would not deal with a risk this way (in percentages). - I would ask the specialist who knows. - question is confusing, not sure what you are asking (9 respondents) - it is very seldom that a major RM action would be taken on the sole results of one sample. - bad question

Note:
Where comments are identical to those for question 9, they are provided by same respondent who just wrote “see above” for this question.

Question 11:

Option	**Relevant comments**
95-100%	- I would accept the result as “true”, but unless the re-sample test was also true I would assess the risk as “acceptable”, based on the “normal” background rate of 1/10’000 samples positive. (i.e. no system is perfect). - I am glad to see that this was hypothetical. Although a city could not test for this organism 10,000 times, as it would take a lot of time, water and money to do so. - What do you mean by one in every 10,000 water samples? Are you testing only 1 in 10,000 or are all 10,000 tested for Giardiosis? How many samples are tested for Giardiosis? - But are they viable! / There is always a margin of error. No test is ever 100%. Major decisions are not based on 1 test alone, for this reason. - Without getting into the mathematics too deep (not sure I can do it without a few hours of homework, etc.), but using reason I would say that: - pretty much 100% of the time when *Giardia* was there (in detectable limits), it was detected; - 2% of the time when it was negative, it was there; - so every time it showed up (1/10,000) it was also present (in detectable quantities) 200 times more when it wasn’t detected. - *Giardia* testing is done on 5000 litres of water or more per test (bacterial done on 1000 ml test), therefore the more water passing through the filter, the more likely *Giardia* will be found. However chlorine has shown to inactivate *Giardia* so those negative tests may in fact have *Giardia*. - a logical guess? - seems likely, but how important is this in terms of health risk? - since 99.9% of the test would be true if the pathogen is above the detection level, and 99.9% falls within 90% to 100%. - I’d have good confidence in that test result but I’d still check into the water system to see what’s going on – if all systems are operational and the WS is capable of removing *Giardia* I’d question how the positive sample occurred. - it would be difficult for a missed positive result to occur within a 99.9% detection level. Thus if the result is positive it‘s almost certain that *Giardia* is present. - Our experience has been that *Giardia* testing is extremely difficult. We have obtained the equipment from BCCDC and identifies *Giardia* in our city’s water system every time we have conducted tests. - 0.1%% of tests are false negatives. 2% of tests are false positives. (2 respondents) - I will treat any positive result as true until follow-up tests can be completed. I refuse to second guess the accuracy/ validity of a test that has been approved for use. - but obviously it depends on where, when, how the sample was taken. Is it representative? Is it biased? - I apologize for the brief answers. This is as much time as I can take for

	this. - 99.9% (2 respondents) - Only have 0.01% chance of not detecting contaminant when it is actually there. 2% chance of not not detecting contaminant. - 99.9% x 98% = 97.9 ~ 98% accurate. - Prefer to be safe than sorry, since the detection limit is 99.9% for positive. However would treat as positives. - Confirmation w/ resampling, or certainty might depend on other circumstances (are we expecting it?). - 999/1000 will show true positive; 20/1000 will show false positive. - Wording of question is a little difficult; yes the *Giardia* cysts are above the standard methods detection limit, but is the 1/10,000 sample the # detected, or is that the hypothetical detection limit?? Assuming the true detection in the system reflects 1/10,000 samples to actually have *Giardia* cysts, & that 99.9% of tests containing *Giardia* cysts will show positive, but 2% of the tests will show a false positive, when *Giardia* is actually not there, the tests are skewed in favour of positive assurance; but if detection is only 1/10,000, & we actually detected a cyst (a positive), then in all likeliness, it is a true positive.
80-95%	- very likely confidence level is way up. - 99.9% of 10,000 = 10 samples that could be positive but will test negative; 2% of 10,000 = test positive when negative. - Hard to interpret question. I started wondering over how many years the samples were from, where in the system, any outstanding occurrences to the water system prior to positive sample. Also I know that sampling for *Giardia* cysts is difficult and that the presence of *Giardia* cysts doesn't always link to an outbreak or illness. The question seems to challenge my understanding of risk and accuracy interpretation. - it's been a while since I took probabilities & stats!! - If I understand the question there could be 10 false positives results & 200 false negative results in 10,000 samples given the test. I would find the result to be very likely but nor certain. - most inspectors have not taken any training in probability or if they have, it was long time ago.
50-80%	- the likelihood of sampling error significantly lowered my answer for #11. - a probable positive *Giardia* once every 10,000 water samples on its own would not be considered a high hazard issue.
20-50%	- none
5-20%	- the accuracy is not 100%; it is possible to have false positives. - false positives can occur in lab analysis of the sampling. - ± 10%; $1/10^4 = 0.01\%$.
0-5%	- a false positive result is 20x more likely than a false negative. If 1/10,000 is detected, the variance is high, so likelihood is low. - at first I thought the rate of sampling was 1 in 10,000 persons for the sample population. After re-reading the question for sample # I saw the 1/10,000 was the rate of positive samples. Respondents may misread this question, especially if you are looking for "first instinct" responses. - *Giardia* is showing up in only 1/10,000 tests when the standard for the analytical test says it will show positive for 99.9% (or 1/1000 will not show up): it is extremely unlikely to be a true positive.

	- out of 10,000 samples, 10 samples may be negative for positive testing, while 200 may be false positives. This ratio is ~ 5%. There would be a higher risk of false positives. - 0.1% F-; 2% F+; 2% / 0.1% = 20x = 5%.
No idea	- I find the question confusing and don't have the time to sit and think about it. - Other more important factors have to be made available. I.e. (1) Number of confirmed cases in the population concerning the specific pathogen; (2) relative risk to population.
missing	- Haven't got time to make sense of this question. - I'd have to be there!

Question 13:
- hard and difficult concept with respect to risk management.
- nowadays, for every scientific study there is an equal study disproving a technology or study.
- we follow our policy depending on results obtained / situations.

Question 14
- Ever since Walkerton and North Battleford waterborne outbreaks, the provincial protocol is very specific on what actions should be taken depending on the bacteriological results. I believe this protocol was long due and makes decision making easier when dealing with water related questions.
- Continued education in water is an absolute. Treatment strategies change daily and it is imperative for EHO/PHI to know what the results mean and how to…
- EHOs must take the responsibility of monitoring all tests results for all drinking water systems.
- Little involvement with water issues in a city health department
- This takes longer than 10-15 min to complete
- Water in rural areas is a true concern as many operators have limited training. Also PHI should be more active in the monitoring process
- In British Columbia we are currently using new regulations and trying to get all water systems to a good, protected level
-Thank you; it is good to have educated people doing these things for us in the field; people often won't listen to public health, but if the university profs talk!!!
- It is important to recognize and address water safety concerns for all Canadians. Often populations which are most vulnerable live in environments where water quality is an issue (i.e. first nations communities, rural areas); not enough importance attached to water quality unless it becomes an issue (reactive, not proactive).
- Water should be considered contaminated unless proven otherwise (chemically or bacterial); an inspector should be conversant in all forms of treatment for chemical and bacterial reduction
- City size systems need people who have training in that size/type of system including assessments as in Q 11-13; small rural systems need staff with knowledge to assist in basic, low cost interventions, improvement, advice (can't afford to hire an engineer)

- License requirements for well drillers should include education to stress use of well water or potable water for drilling, not dugout or slough water
- Drinking water quality is too large an area and now too technical and in-depth for anyone who is not specifically and thoroughly trained in this area and able to commit all the time and continuing education that is required; public health at best should be only a back-up test monitoring source and an initial contact for referral.
- Municipality runs the system. PH gets complaints on aesthetics. When evidence found of a health hazard the management acts appropriately.
-We still fall back on protecting and improving our water sources as being very important. Even with great treatment and operation of some water systems I'd still prefer to drink bottled water in some cases because I am not comfortable with the level of contamination of the source water. Walkerton is a case in point –when agricultural waste contaminates drinking water sources, to the extent that of a chlorinator fails, people will get sick or die. Is that an acceptable source to begin with??
- There is still a surprising amount of Canadians consuming unsafe water (biological contaminants) either at home or through exposure to small water systems at lodges, resorts, small communities. There is a concerning lack of treatment/filtration for even large systems in British Columbia. In rural areas many residents still consume surface water with no treatment whatsoever.
- Water is our most valuable resource
- I would be interested to see the results of your study. Good luck with it .
-Anything that improves the education of public health professionals is a good thing. Unfortunately there is so much under funding now in Alberta and PHIs are stretched so thin, improving their education won't help the public. More resources and more PHIs are desperately needed.
- It would be interesting to know numbers of water treatment plants and which municipalities they serve, as well as which populated areas are dependent solely on wells (for Alberta and Canada for comparison).
- When in doubt throw it out (food); choose to err on the side of safety
- I would like to see public health professionals take a stronger lead in water issues. They should be the first contact and lead agency/professional for water. Water has become a complex issue with many competing priorities/issues with various agencies/resources and activity users. Over the year there has been a lack of recognition of health risks associated with water and an associated lack of interest in water issues. Health professionals need to take a lead role to coordinate all the complex issues associated with water to prevent occurrences such as Walkerton. The public has become complacent on water and lost perspective of water related risks.
- Interesting survey
-This is very interesting and valid questionnaire; please send out your findings to us.
- Hope this helps
- Those with private supplies are ignorant of risks, regular water sampling is not done, often regular water sampling is done for house sale-mortgage only;

individuals will use infested sources such as springs and will even use those posted as unsatisfactory spring sites.

- I have recently completed BCIT environmental Health Program and I consider their water program to be very week, especially with the present day priority of drinking water
- I would guess that you fellows don't work in the real world. Your questions are not clear, take too much effort to understand and answer. Why waste my time?
- Especially in rural areas, blue green algae is becoming a huge issue and techniques to appropriately deal and control will be required.
- Nobody asks me for input (and this is 100%)
- I trust I will get to see the results of the survey
- I am not a full time PHI and I have not dealt with water issues for a while. I am more focused on tobacco at this time.
- Many people argue that bacterial sampling is not the answer to determine whether water is safe to drink. What does a positive total coliform result means? If there are high totals, when you normally don't see totals on that system, what is the risk that the water will make the consumers sick? What are better, practical indicators of water quality that can be used to assess risk?
- I never ceased to be amazed at how excited health workers get about the odd positive sample, even fecal, yet there is what appears to be apathy with regards to day to day operation. For example we have a system that runs a >400 NTU turbidity (yes four hundred) and is not on public notice or BWA. How does one keep a chlorine residual with this level of turbidity? Yet people are doing cartwheels over the odd positive in a grid, when samples are merely an audit. Also we have people lining up to buffet tables to eat thousands of fecal (test results reflect this), and our bathing beach results show thousands also. Plus there is even a standard of allowable E coli in unpasteurized apple juice, 100 per 100ml in 2 out of 5 may have up to 1000.

APPENDIX G

Health Board Orientation Document

To: RHA Health Board
Re: Safe drinking water

The capacity to provide consistently safe drinking water for everyone represents one of the greatest public health advances in history. Contaminated drinking water was a regular source of illness and death by infectious diseases such as typhoid or cholera, diseases which still plague less affluent countries today. Along with improvements in waste disposal and hygiene in affluent countries, safe drinking water now protects against the infectious diseases transmitted by the fecal-oral route. Moreover, by interrupting the fecal-oral circulation of pathogens in a community, drinking water treatment limits infectious disease persistence in the population. So great has been the effect of this intervention that in Canada we barely remember the terrible epidemics that were once a periodic occurrence. This is an excellent example of primary prevention at work in protecting public health.

Assuring that drinking water provided to all citizens is safe is first and foremost a public health responsibility. While designing and supporting the technology that assures safety is an engineering challenge, assuring that water does not serve as a vehicle for the spread of disease remains a public health responsibility. While we are now able to turn on the tap and drink the water without worrying about whether it will make us sick, we must not forget that the basic causes that produced one epidemic after another in the past in every country have not disappeared. There is no reason to slacken our efforts. While justified health concerns have been raised by several chemical hazards (e.g. arsenic, lead, nitrates/nitrites, selenium, fluoride), microbial pathogens still represent the most common and clear waterborne health risk. To keep up with population growth, agricultural and industrial development, globalization, faster travel and their effect on infectious disease transmission, we need to become even more efficient and to develop even better ways to protect population health.

A common problem with public health interventions is that the general public cannot easily tell when these measures are doing their best; the public would only know when they fail to do so, because of the occurrence of otherwise preventable diseases. Drinking water safety faces the same challenge. Events like the Walkerton tragedy remind us that drinking water is not essentially safe by default, but the result of continuous commitment. Hrudey and Hrudey (2004) notes that 334 waterborne outbreaks of infectious origin involving over 15,000 confirmed cases of illness were reported to Health Canada between 1974 and 2003. As far as the microbial cause of the outbreak, 79 were caused by bacteria (*Campylobacter jejuni* - 32, *Salmonella* spp. - 22, *Shigella* spp. - 9), 75 by protozoa (*Giardia lamblia* - 64, *Cryptosporidium* spp. - 10, *Toxoplasma gondii* - 1), 28 by viruses (hepatitis A virus - 13, Norwalk and Norwalk-like viruses - 13, rotavirus - 2) and one by both bacteria and protozoa. The outbreaks occurred in public drinking water systems (21%), semi-public (47%) and private (23%), whereas 9% of the outbreaks were attributed to consumption of untreated surface water or to unknown sources. The numbers likely underestimate the real situation, because not all waterborne outbreaks are recognized, investigated or reported, particularly in small communities where the low number of cases may be difficult to detect against background levels of disease.

In Canada we have the capacity to provide safe drinking water to all our residents. Not only are we blessed with abundant water sources, but we also have the expertise, technology and resources to assure drinking water quality to the highest standards. This mission is already facilitated by the work of the Canadian public health system and environmental agencies for over a century, which has greatly reduced the available pathogens in number and type as well as water sources contamination. As a result, drinking water in large communities in Canada is as safe as can reasonably be achieved for most of the time. To assure this level of safety is consistently achieved we need quality management approaches to improve our capacity under both normal and challenging conditions, and more upstream interventions to address causes of water contamination. We also have to bring this higher standard to numerous small and private water supplies often operated by untrained individuals with inadequate or nonexistent safety barriers.

As representatives of public trust, the RHA health board has to assure that all their citizens are consistently provided with safe drinking water. Below are several areas where members of the health board can inquire to understand how their health agency is discharging their public health responsibilities for safe drinking water. The list is adapted from Hrudey and Hrudey (2004), and the above recommendations for drinking water safety (sections 4.1. and 4.2.).

Regional strategy

1. What is the regional safe drinking water policy?
2. What are the safe drinking water objectives for the current period?
3. Who regulates the water (i.e. which governmental agencies)? Which drinking water systems do they regulate? Are there other public water systems not covered by the above regulatory agencies? Who assures drinking water safety for these systems?
4. How do different stakeholders co-operate to assure drinking water safety?
5. Who monitors the water quality routinely (i.e. laboratories)? Who do they report to? What checks are maintained to assure they are accurate?
6. What programs are in place to assure drinking water safety for private water systems? How effective are they?
7. What training do enforcement officers have? How often do they check water quality? Are their checks unannounced? Who verifies that they have the necessary knowledge to assure safe drinking water?
8. What training and support do water operators of regulated systems receive? What training and support do water operators of unregulated public water systems receive? Do they receive any public health training to understand their role and responsibilities for consumer health? What are the continuing education opportunities for each category of operators?

9. Is there a formal system to assure learning from the experience of previous failures and near failures?
10. Is there a quality management strategy in place for these systems?
11. Is there a third-party audit of their operation? What is their mandate? How frequently is this done? Who are the audit findings reported to?
12. What long-term strategies are considered to assure sustainable safe drinking water?

System-specific inquiries (e.g. the municipal water system)

1. What is the raw water source for the local drinking water?
2. What are the main threats of contamination to this water source?
3. What are the seasonal trends in raw water quality and flow that can affect drinking water availability and safety?
4. What influence can unusual weather events have on raw water quality?
5. Considering the above, how is raw water treated to assure consistently safe drinking water? What initiatives are in place to control water source contamination? What safety barriers are in place? How is the integrity of the water system verified? How are unusual challenges or barrier failures detected and controlled?
6. Is there a risk management plan in place that specifies operational procedures, verification of barrier integrity, emergency response, reporting, evaluation and audits?
7. What is the training level of the water operators? What continuing education opportunities do they have?
8. What incentives are they provided for identifying problems and for improving performance?
9. Who is in charge of the water system? What is their training and experience? What opportunities are provided to increase their expertise and learn from their peers?
10. Are close calls reported and used to improve operator and system performance?
11. Is there a water system improvement plan? Are improvements prioritised to address the high risks first?

Reference:

Hrudey, S. E. and E. J. Hrudey (2004). Safe Drinking Water - Lessons from Recent Outbreaks in Affluent Nations. London, UK, IWA Publishing: 514 pp.